Hurricane *i*

Integrated Ti:Sapphire Amplifier System

User's Manual

Spectra-Physics
Lasers & Photonics

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Preface

This manual contains information you need in order to safely operate, maintain, and perform routine service for your *Hurricane i* system. The system comprises the *Hurricane i* assembly, which includes the regenerative amplifier along with the seed laser and pump laser, the power supplies and chillers needed for the two lasers included in the assembly, the synchronization control module for the system (the SDG II), and the portable computer with pre-installed Windows®* -based control software for operating the *Hurricane i* system.

Chapter 1, "Introduction," contains a brief description of the *Hurricane i* system and its components.

Chapter 2 contains vital important about safety. The *Hurricane i* is a Class IV laser and, as such, emits laser radiation which can permanently damage eyes and skin. This section contains information about these hazards and offers suggestions on how to safeguard against them. To minimize the risk of injury or expensive repairs, be sure to read this chapter—then carefully follow these instructions.

"Laser Description" includes basic laser theory regarding the Ti:sapphire crystal and a description of the chirped-pulse amplification technique used in the *Hurricane i*. It also contains a more detailed description of the *Hurricane i* amplifier. System specifications are also included.

The next chapter describes the *Hurricane i* connections, controls and indicators and is followed by a chapter that outlines how to prepare your laboratory for the installation of the system. Spectra-Physics will send a service representative to install the *Hurricane i* the first time. Spectra-Physics does not guarantee the performance of this system unless the *Hurricane i* is installed by an authorized Spectra-Physics representative. This chapter includes outline drawings and electrical and mechanical specifications.

Operating the *Hurricane i* amplifier is relatively simple using the control software provided with the system. This software is described in Chapter 6, "Operation."

Chapter 7, "Optical Layout," describes the beam path and components of the *Hurricane i* assembly. An understanding of how the amplifier operates is essential to understanding the maintenance procedures listed in Chapter 8, "Maintenance and Troubleshooting." The latter contains procedures that help keep the *Hurricane i* performing optimally. The section on troubleshooting is intended to help you guide your Spectra-Physics field service engineer to the source of any problems.

**Windows is a trademark of Microsoft Corporation.*

Do not attempt repairs yourself while the unit is still under warranty; instead, report all problems to Spectra-Physics for warranty repair.

The last part of the manual covers service and includes a replacement parts list and a list of world-wide Spectra-Physics service centers you can call if you need help.

This product has been tested and found to conform to "Directive 89/336/EEC for electromagnetic Compatibility." Class A compliance was demonstrated for "EN 50081-2:1993 Emissions" and "EN 50082-1:1992 Immunity" as listed in the official *Journal of the European Communities*. It also meets the intent of "Directive 73/23/EEC for Low Voltage." Class A compliance was demonstrated for "EN 61010-1:1993 Safety Requirements for Electrical Equipment for Measurement, Control and Laboratory use" and "EN 60825-1:1992 Radiation Safety for Laser Products." Refer to the "CE Declaration of Conformity" statements in Chapter 2.

This product conforms to the requirements of 21 CFR 1040.10 CDRH and are compliant to Underwriters Laboratory UL1950 and are listed as ULR for recognized components. This equipment has been designed and tested to comply with the limits for a Class A digital device pursuant to Part 15 of the FCC Rules.

If you encounter any difficulty with the content or style of this manual, please let us know. The last page is a form to aid in bringing such problems to our attention.

Thank you for your purchase of Spectra-Physics instruments.

Regulatory Specifications

CE Electrical Equipment Requirements

For information regarding the equipment needed to provide the electrical service listed under "Service Requirements" at the end of Chapter 3, please refer to specification EN-309, "Plug, Outlet and Socket Couplers for Industrial Uses," listed in the official *Journal of the European Communities.*

Environmental Specifications

The environmental conditions under which the laser system will function are listed below:

Indoor use

Altitude:	up to 2000 m
Temperatures:	18° C to 35° C
Maximum relative humidity:	80% non-condensing for temperatures up to 31° C.
Mains supply voltage:	do not exceed ± 10% of the nominal voltage
Insulation category:	II
Pollution degree:	2

FCC Regulations

This equipment has been tested and found to comply with the limits for a Class A digital device pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

Modifications to the laser system not expressly approved by Spectra-Physics could void your right to operate the equipment.

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Warning Conventions

The following warnings are used throughout this manual to draw your attention to situations or procedures that require extra attention. They warn of hazards to your health, damage to equipment, sensitive procedures, and exceptional circumstances. All messages are set apart by a thin line above and below the text as shown here.

Laser radiation is present.

Condition or action may present a hazard to personal safety.

Condition or action may present an electrical hazard to personal safety.

Condition or action may cause damage to equipment.

Action may cause electrostatic discharge and cause damage to equipment.

Condition or action may cause poor performance or error.

Text describes exceptional circumstances or makes a special reference.

Do not touch.

Appropriate laser safety eyewear should be worn during this operation.

Refer to the manual before operating or using this device.

Standard Units

The following units, abbreviations, and prefixes are used in this Spectra-Physics manual:

Quantity	Unit	Abbreviation
mass	kilogram	kg
length	meter	m
time	second	s
frequency	hertz	Hz
force	newton	N
energy	joule	J
power	watt	W
electric current	ampere	A
electric charge	coulomb	C
electric potential	volt	V
resistance	ohm	Ω
inductance	henry	H
magnetic flux	weber	Wb
magnetic flux density	tesla	T
luminous intensity	candela	cd
temperature	celcius	C
pressure	pascal	Pa
capacitance	farad	F
angle	radian	rad

Prefixes								
tera	(10^{12})	T	deci	(10^{-1})	d	nano	(10^{-9})	n
giga	(10^{9})	G	centi	(10^{-2})	c	pico	(10^{-12})	p
mega	(10^{6})	M	mill	(10^{-3})	m	femto	(10^{-15})	f
kilo	(10^{3})	k	micro	(10^{-6})	μ	atto	(10^{-18})	a

Abbreviations

The following abbreviations are used in this manual:

AC	alternating current
AOM	acousto-optic modulator
AR	antireflection
C	Centigrade
CDRH	Center of Devices and Radiological Health
CPA	Chirped Pulse Amplification
CW	continuous wave
DC	direct current
E/O	electro-optic
F	Fahrenheit
fs	femtosecond or 10^{-15} second
GVD	group velocity dispersion
HR	high reflector
IR	infrared
OC	output coupler
ps	picosecond or 10^{-12} second
RF	radio frequency
SCFH	standard cubic feet per hour
SPM	self phase modulation
TEM	transverse electromagnetic mode
Ti:sapphire	Titanium-doped Sapphire
λ	wavelength

Unpacking and Inspection

Unpacking Your Laser

Your *Hurricane i* laser was packed with great care, and its container was inspected prior to shipment—it left Spectra-Physics in good condition. Upon receiving your system, immediately inspect the outside of the shipping containers. If there is any major damage (holes in the containers, crushing, etc.), insist that a representative of the carrier be present when you unpack the contents.

Once uncrated, carefully inspect your laser system as you unpack it. If any damage is evident, such as dents or scratches on the covers or broken parts, etc., immediately notify the carrier and your Spectra-Physics sales representative.

Keep the shipping containers. If you file a damage claim, you may need them to demonstrate that the damage occurred as a result of shipping. If you need to return the system for service at a later date, the specially designed container assures adequate protection.

Warning!

Spectra-Physics considers itself responsible for the safety, reliability, and performance of the *Hurricane i* laser only under the following conditions:

- All field installable options, modifications, or repairs are performed by persons trained and authorized by Spectra-Physics.
- The equipment is used in accordance with the instructions provided in this manual.

System Components

- *Hurricane i* laser head
- *Mai Tai* power supply
- *Evolution-15* power supply
- *SDG II* controller
- Notebook computer with control software pre-installed
- A chiller with tubing and fittings and its own user's manual
- An accessory kit (see below)

Accessory Kit

Included with the laser system is this manual, a test summary, a packing slip listing all the components shipped with this order, and an accessory kit containing the following items:

- Hardware for mounting the *Hurricane i* laser head to a horizontal base plate
- RS-232 serial control cable
- Interface control software on one CD-ROM (backup)
- *Fuses for the power supplies*

  Model J40 10 A fuses (2) (*Mai Tai*)
- D-sub jumper plugs for the REMOTE and ANALOG ports on the *Mai Tai* power supply (not used on this system)
- Specification summary form

Chapter 1 Introduction

The *Hurricane i*® system amplifies the output of a mode-locked Ti:sapphire laser to produce high-power, ultrafast pulses. The components needed to produce these femtosecond, milli-Joule pulses at kilo-Hertz repetition rates are provided in a single, compact assembly. Inside this assembly are the *Mai Tai* seed laser, the pulse stretcher, regenerative amplifier and pulse compressor, as well as the *Evolution-15* pump laser (which excites the regenerative amplifier). Refer to Figure 1-1

The mode-locked, Ti:sapphire *Mai Tai* seed laser contains its own pump laser. The *Mai Tai* and its component lasers are described in detail in its own manual included with the *Hurricane i* system. The *Evolution-15* is a diode-pumped, Q-switched, frequency-doubled pump laser, and it, too, is described in detail its own manual shipped with this system.

Control of the *Hurricane i* is via comprehensive, yet intuitive, Windows®*-based control software provided pre-installed on a laptop computer included with the system. Sophisticated onboard diagnostics enable full control of system functions through the software interface.

Amplification takes place in the *Hurricane i* when a pulse selected from the *Mai Tai* seed laser passes through the Ti:sapphire amplifier rod, which has been optically excited by the *Evolution-15* pump laser. A single pass of an optical pulse through such a rod will result in about a 3 x amplification; however regenerative amplification enables the pulse to pass multiple times through the rod, resulting in a much higher overall gain. A seed pulse of only a few nano-Joules can be amplified by a factor of 10^6.

Normally, the damage threshold of the optical elements limits the maximum energy to which the pulse can be amplified. However, using Chirped Pulse Amplification (CPA) allows the *Hurricane i* to operate without risk of optical damage. Originally developed for radar systems, CPA involves temporally stretching the pulse to reduce its peak power, then amplifying the pulse while it is at reduced power, and finally compressing the amplified pulse to near its original duration.

The compact, enclosed amplifier with active cooling provides stable operation and reduces sensitivity to environmental changes. The compressor section allows easy correction of the higher order phase distortion that is typical of ultrafast amplifier systems.

The *Hurricane i* produces pulses slightly longer than 100 fs near 800 nm at a repetition rate of 1 kHz. An option exists for 5 kHz output. Contact your Spectra-Physics representative for more information about this option.

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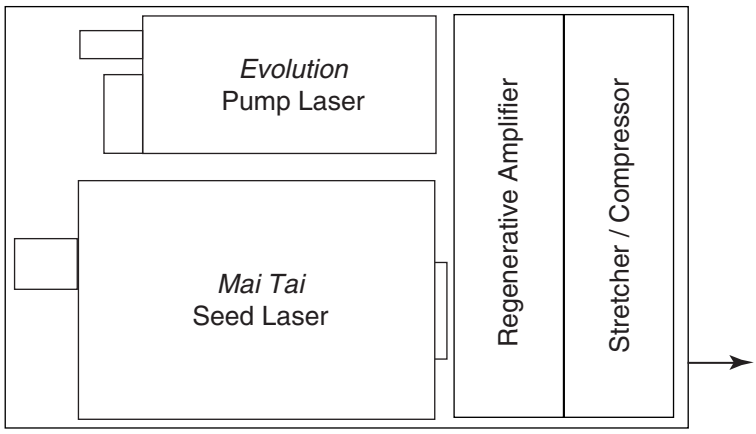


Figure 1-1: Block Diagram of the *Hurricane i* Assembly

A *Hurricane i* system comprises six main components:

- the *Hurricane i* assembly
- a notebook PC with LabWindows*™ control software
- the Synchronization and Delay Generator (*SDG II*)
- the power supply for the *Mai Tai* laser
- the power supply for the *Evolution-15* laser
- the chiller

In addition to these components, a small motion controller is included to fine-tune the compressed *Hurricane i* output.

A detailed description and instructions for operating and maintaining the *Hurricane i* are included in this manual. The reader is referred to the respective manuals for descriptions of the *Mai Tai* and *Evolution-15* internal laser systems.

Note

The user manuals for the *Mai Tai* and *Evolution-15* lasers contain instructions for operating these lasers as stand-alone systems. The operating instructions in this *Hurricane i* manual supersede those in the separate user manuals.

Note in particular that the version of the *Mai Tai* used in the *Hurricane i* is not a tunable laser, but is optimized to operate at a single wavelength

*LabWindows is a trademark of National Instruments Corporation.

Chapter 2 Laser Safety

The Spectra-Physics *Hurricane i* amplifier is a Class IV High Power Laser whose beam is, by definition, a safety and fire hazard. Take precautions to prevent accidental exposure to both direct and reflected beams. Diffuse as well as specular beam reflections can cause severe eye or skin damage.

Because the output wavelength is in the infrared, the *Hurricane i* output beam is invisible and therefore especially dangerous. This type of infrared radiation passes easily through the cornea of the eye, and, when

Precautions for the Safe Operation of Class IV High Power Lasers

- Wear protective eyewear at all times; selection depends on the wavelength and intensity of the radiation, the conditions of use, and the visual function required. Protective eyewear is available from suppliers listed in the *Laser Focus World*, *Lasers and Optronics*, and *Photonics Spectra* buyer's guides. Consult the ANSI and ACGIH standards listed at the end of this section for guidance.
- Maintain a high ambient light level in the laser operation area so the eye's pupil remains constricted, reducing the possibility of damage.
- Avoid looking at the output beam; even diffuse reflections are hazardous.
- Avoid wearing jewelry or other objects that may reflect or scatter the beam while using the laser.
- Use an infrared detector or energy detector (IR viewer) to verify that the laser beam is off before working in front of the laser.
- Operate the laser at the lowest beam intensity possible, given the requirements of the application.
- Expand the beam whenever possible to reduce beam power density.
- Avoid blocking the output beam or its reflections with any part of the body.
- Establish a controlled access area for laser operation. Limit access to personnel trained in the principles of laser safety.
- Enclose beam paths wherever possible.
- Post prominent warning signs near the laser operating area (Figure 2-1).

- Set up experiments so the laser beam is either above or below eye level.
- Set up shields to prevent any unnecessary specular reflections or beams from escaping the laser operation area.
- Set up a beam dump to capture the laser beam and prevent accidental exposure (Figure 2-2).

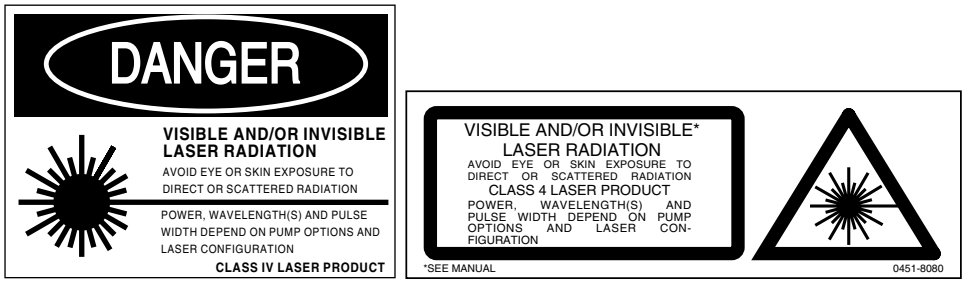


Figure 2-1: Labels Appropriate for Warning Signs

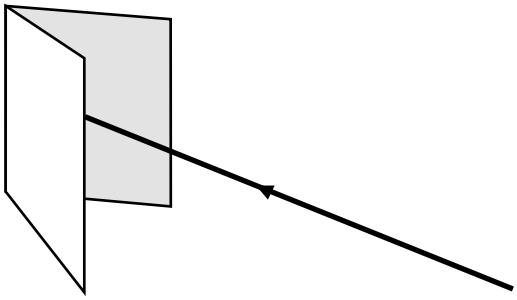


Figure 2-2: Folded Metal Beam Target

Caution!

Use of controls or adjustments, or the performance of procedures other than those specified herein may result in hazardous radiation exposure.

Follow the instructions contained in this manual for safe operation of your laser. At all times during operation, maintenance, or service of your laser, avoid unnecessary exposure to laser or collateral radiation* that exceeds the accessible emission limits listed in "Performance Standards for Laser Products," *United States Code of Federal Regulations*, 21CFR1040 10(d).

* *Any electronic product radiation, except laser radiation, emitted by a laser product as a result of, or necessary for, the operation of a laser incorporated into that product.*

Mode-Locked Laser

The *Hurricane i* uses a CW mode-locked Ti:sapphire laser (the *Mai Tai*) as a seed beam source. The beam from this laser is hazardous. Refer to the *Mai Tai User's Manual* for additional safety information.

Pump Laser

The *Hurricane i* uses a pulsed, frequency-doubled Nd:YLF laser (the *Evolution-15* laser) as a pump source. The beam from this laser is hazardous. Refer to the *Evolution-15 User's Manual* for additional safety information.

Safety Devices

Emission Indicators

After pressing the ON button on the *Evolution-15* display screen, a display on the same screen flashes to warn that the *Evolution-15* is capable of emitting laser light. There is a 3 second delay between the time the *Evolution-15* LED comes on and the time when *Evolution-15* can emit laser light. During normal operation, light from the *Evolution-15* is entirely contained within the *Hurricane i* assembly.

An emission indicator light on the front of the *Hurricane i* (Figure 2-3) also turns on at this time. *Whether the Mai Tai seed laser is on or not, the Hurricane i is now capable of emitting high power laser light*.

In some circumstances it is possible for a small amount of light from the *Mai Tai* laser to pass through the *Hurricane i* and to be emitted from the output port, even if other system components are turned off. This will not occur if the proper operating procedures are followed.

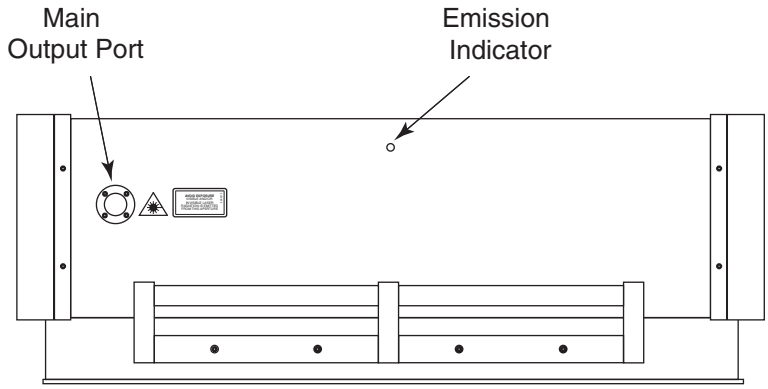


Figure 2-3: *Hurricane i* Emission Indicator

Shutter

The internal electromechanical shutters are controlled via the control software or via the RS-232 interface. The interlock fault and fail-safe modes are the *closed* position.

There are three external output ports for laser emission: two for the *Hurricane i* output and one optional port for the *Mai Tai* laser output. During normal operation, only one *Hurricane i* output port is used. The other port should be sealed. *Mai Tai* laser output is available as an option for the user.

Note that the *Mai Tai, Hurricane i and Evolution-15* each contain internal shutters that are individually computer-controlled. There is no one control that opens or closes all of them at the same time. Refer to the respective user's manuals included with the *Hurricane i* system for more information about these shutters.

Interlock Keyswitches

Two keyswitches provide interlock safety by preventing unauthorized personnel from using the *Hurricane i* system when the keys are turned to the "off" position and the keys are removed. Turning a key to the "on" position closes the interlock and allows the diode lasers in the power supplies to be energized (if the ac power switches are also on).

These keyswitches are on the *Mai Tai* and the *Evolution-15* power supplies. Refer to the respective user's manuals included with the *Hurricane i* system for more information on these keyswitches.

Switches and Power Indicators

Switches on the *Mai Tai* and the *Evolution-15* power supplies provide ac power to the system, and associated LEDs, when on, indicate that ac power is applied to the system control circuits. Refer to the respective user's manuals included with the *Hurricane i* system for more information on these components.

Cover Safety Interlocks

The *Hurricane i* is not intended for routine operation with the covers removed. The cover safety interlock is activated whenever the cover is opened and terminates *Hurricane i* laser action by switching off the *Evolution-15*. The *Hurricane i* should not be operated unless this interlock protection is available. However, the interlock can be overridden for maintenance or service needs. Chapter 8, "Maintenance and Troubleshooting," describes the procedure for defeating the interlock.

The cover interlock on the *Hurricane i* **does not** deactivate the *Mai Tai* laser. When the *Hurricane i* cover is removed and the *Mai Tai* is on, be extremely careful to avoid exposure to the laser beams or its reflections.

Both the *Mai Tai* and the *Evolution-15* lasers are sealed at the factory to prevent contamination. Opening these systems will void your warranty.

The power supplies are is not intended to be operated with the covers removed. Therefore, *there are no cover interlocks*. Non-interlock warning labels are attached to the power supplies. Refer to the *Mai Tai* and the *Evolution-15* user's manuals for more information. These labels state that power must be off before the power supply covers can be removed.

Fuses

Refer to the *Mai Tai* and the *Evolution-15* user's manuals supplied with the *Hurricane i* for the values and locations of the fuses in those systems. The fuse for the *Hurricane i* is located on the *SDG II*.

Table 2-1: Fuse Ratings for *SDG II*

120 Vac	220 Vac
F1AH 250V, Slow Blow	F0.5AH 250V, Slow Blow

Maximum Emission Levels

The following is the maximum emission level possible for this *Hurricane i* amplifier system. Use this information for selecting appropriate laser safety eyewear and implementing appropriate safety procedures. This value does not imply actual system power or specifications.

Emission Wavelength	Maximum Power
690 to 1080 nm	3 W
Pump laser emission 527 nm	20 W
Fiber diode laser emission: 809 nm	26 W, CW, each fiber

CDRH Requirements for Operating the Mai Tai Using the RS-232 Interface and Command Language

The *Hurricane i* laser system complies with all CDRH safety standards when operated using the *Hurricane i* control software provided with the system. However if the *Hurricane i* or the *Mai Tai* laser are operated using the command language interface, you must provide an emission indicator in order to satisfy CDRH regulations.

- **An emission indicator**—that indicates laser energy is present or can be accessed. It can be a "power-on" lamp, a computer display that flashes a statement to this effect, or an indicator on the control equipment for this purpose. It need not be marked as an emission indicator so long as its function is obvious. *Its presence is required on any control panel that affects laser output, including the computer display panel.*

Maintenance Necessary to Keep this Laser Product in Compliance with CDRH Regulations

This laser product complies with Title 21 of the *United States Code of Federal Regulations*, Chapter 1, sub-chapter J, parts 1040.10 and 1040.11, as applicable. To maintain compliance with these regulations, once a year, or whenever the product has been subjected to adverse environmental conditions (e.g., fire, flood, mechanical shock, spilled solvent, etc.), check to see that all features of the product identified on the CE/CDRH Radiation Control Drawing (found later in this chapter) function properly. Also, make sure that all warning labels remain firmly attached.

Verify that removing the auxiliary interlock connector on the *Mai Tai* power supply prevents laser operation (see the *Mai Tai* user's manual).

1. Verify the laser can only be turned on when the keyswitch of both power supplies are in the ON position, and that the keys can only be removed when the switches are in the OFF position.
2. Verify the emission indicator provides a visible signal when the laser emits accessible laser radiation that exceeds the accessible emission limits for Class I.*
3. Verify the time delay between turn-on of the emission indicator and starting of the laser; it must give enough warning to allow action to avoid exposure to laser radiation.
4. Verify the beam attenuator (shutter) operates properly when commanded from the laptop PC controller and that it closes when the controller is disconnected or the keyswitch is turned off. Verify it actually blocks access to laser radiation.

* *0.39 µW for continuous-wave operation where output is limited to the 400 to 1400 nm range.*

CE/CDRH Radiation Control Drawings

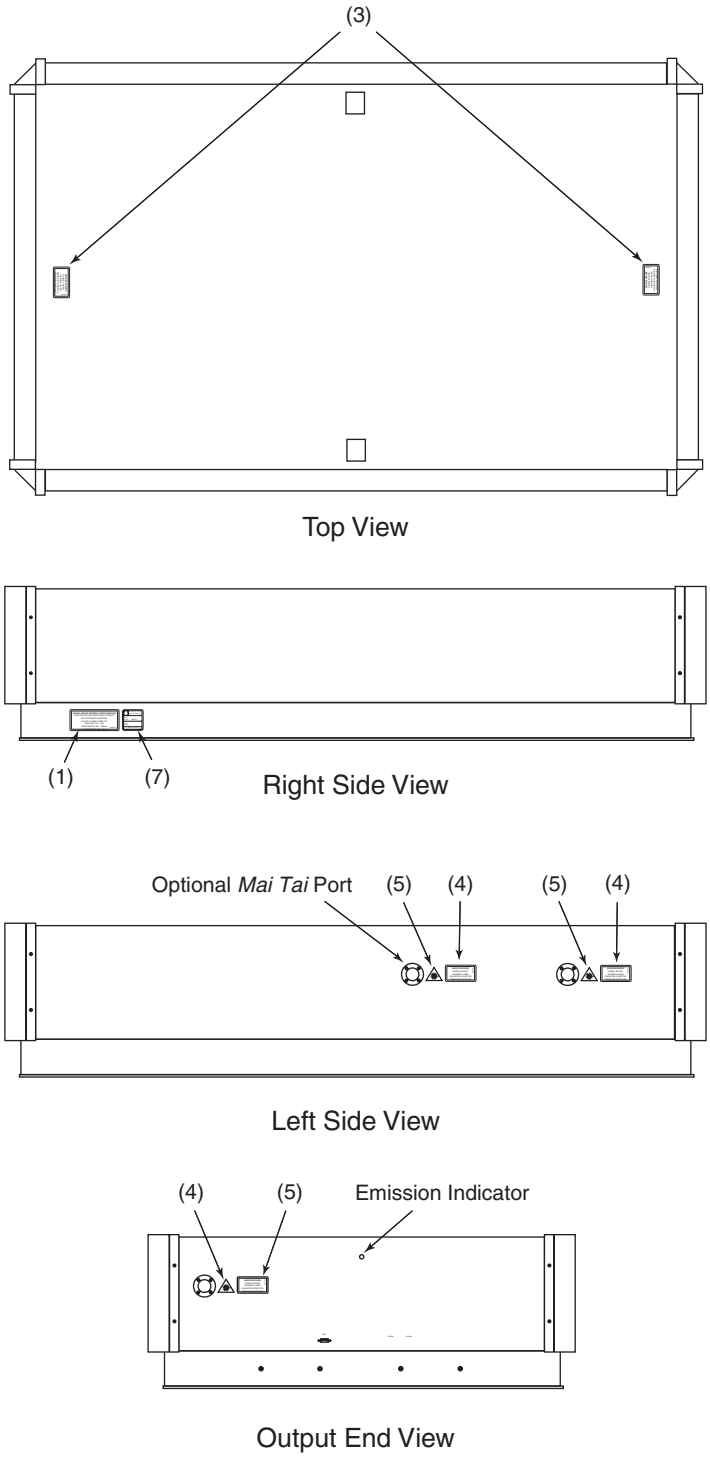
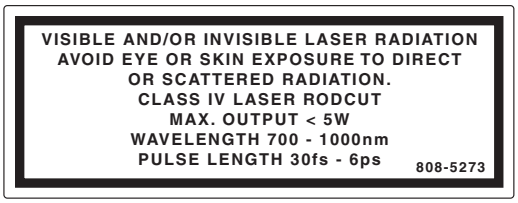
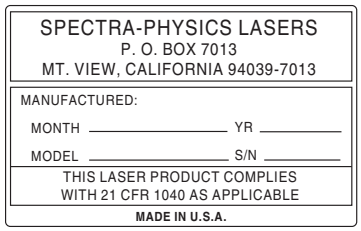


Figure 2-4: *Hurricane i* CE/CDRH Radiation Control Drawing (see Labels in Figure 2-5)


VISIBLE AND/OR INVISIBLE LASER RADIATION
AVOID EYE OR SKIN EXPOSURE TO DIRECT
OR SCATTERED RADIATION.
CLASS IV LASER RODCUT
MAX. OUTPUT < 5W
WAVELENGTH 700 - 1000nm
PULSE LENGTH 30fs - 6ps
808-5273

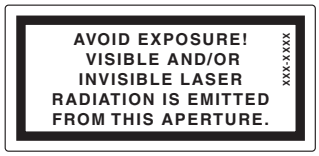
CE Warning Label (1)



Identification/Certification Label (2)

VISIBLE AND/OR INVISIBLE LASER RADIATION
WHEN OPEN AND INTERLOCK DEFEATED
AVOID EYE OR SKIN EXPOSURE TO DIRECT
OR SCATTERED RADIATION.
CLASS IV LASER PRODUCT
808-5275

Danger–Interlocked Housing Label (3)



CE Aperture Label (4)
Part 1

CE Aperture Label (5)
Part 2

CE Electrical Warning Label (6)

Figure 2-5: CE/CRDH Labels

Table 2-2: Label Translations

Label	French	German	Spanish	Dutch
CE Warning Label (1)	Rayonnement visible et/ou invisible exposition dangereuse de l'œil ou de la peau au rayonnement direct ou diffus. Appareil a laser de Classe 4. Puissance maximum 5 W. Longueur D'onde 700−1000 nm. Duree d'impulsion 30 fs−6 ps	Austritt von sichtbarer und/ oder unsichtbarer Laserstrahlung. Augen- und Hautkontakt mit direkter Strahlung oder Streustrahlung vermeiden. Laser Klasse IV Maximale Ausgangsleistung < 5 W Wellenlänge 700 - 1000 nm Pulsbreite 30 fs - 6 ps	Radiación láser visible y/o invisible. Evitar la exposición de los ojos o la piel a la radiacion, ya sea directa ó difusa. Producto láser Clase IV. Potencia máxima <5 W. Longitud de onda: 700−1000 nm. Longitud de pulso: 30 fs−6 ps.	Zichtbare en/of onzichtbare* laser straling. Vermijd blootstelling aan ogen of huid door directe of gereflecteerde straling. Klasse 4 laser produkt; 532 nm, maximaal uittredend vermogen 15 W. *zie handleiding
CE Aperture Label (3)	Exposition Dangereuse – Un Rayonnement laser visible et/ou invisible est emis par cette ouverture.	Nicht dem Strahl aussetzen! Austritt von sichtbarer und/ oder unsicht-barer Laserstrahlung	! Evitar exponerse ¡ Atraves de esta apertura se emite radiacion laser visible y/ o invisible	Vanuit dit apertuur wordt zichtbare en onzichtbare laserstraling geemiteerd! Vermijd blootstelling!
CE Non-Interlocked Label (4)	Rayonnement Laser dangereux visible et/ou invisible en cas D'Ouverture et lorsque la securite est neutralisse; exposition dangereuse de l'œil ou de la peau au rayonnement dirct ou diffus. Appareil a laser de Classe 4	Austritt von sichtbarer und/ oder unsichtbarer Laserstrahlung bei geöffneter Abdeckung und überbrückter Sicherheitsschaltung. Augen- und Hautkontakt mit direkter Strahlung oder Streustrahlung vermeiden. Laser Klasse IV.	Radiacion laser visible y/o invisible al abrir con el seguro anulado. Evitar la exposicion de los ojos o la piel a la radiacion, ya sea directa o difusa. Producto laser Clase IV	Zichtbare en niet zichtbare laser-straling wanneer geoend; vermijd blootsteling aan huid of oog aan disecte straling of weerkaatsingen.

CE Declaration of Conformity

We,

Spectra-Physics, Inc.
Solid-State Lasers
1330 Terra Bella Avenue
Mountain View, CA. 94043
United States of America

declare under sole responsibility that the

***Hurricane i* Integrated, Ti:Sapphire Regenerative Amplifier System with SDG II Controller,**

manufactured after July 1, 1999,

meets the intent of EMC Directive 89/336/EEC: 1989, for electromagnetic compatibility and 73/23/EEC: 1973, for low voltage directives. Compliance was demonstrated to the following specifications as listed in the official *Journal of the European Communities*:

EMC Directive 89/336/EEC: 1989

EN 50081-2: 1993 (Emissions)

EN 55011: 1998, CISPR 11: 1997, Class A radiated and conducted emissions

EN 50082-2: 1995 (Immunity)

IEC 801-2 Electrostatic Discharge
IEC 801-3 RF Radiated
IEC 801-4 Fast Transients

Low Voltage Directive 73/23/EEC: 1973

EN61010-1: 1996, Safety requirements for electrical equipment for measurement, control, and laboratory use—Part 1: General Requirements

EN60825-1: 1997, Safety of laser products—Part 1: Equipment classification, requirements, and users guide

I, the undersigned, hereby declare that the equipment specified above conforms to the above Directives and Standards.

Bruce Craig
Director of Engineering and Marketing

Spectra-Physics
Lasers & Photonics

Solid-State Lasers
April 5, 2002

Sources for Additional Information

The following are some sources for additional information on laser safety standards, safety equipment, and training.

Laser Safety Standards

Safe Use of Lasers (Z136.1: 1993)
American National Standards Institute (ANSI)
11 West 42nd Street
New York, NY 10036
Tel: (212) 642-4900

Occupational Safety and Health Administration (Publication 8.1-7)
U. S. Department of Labor
200 Constitution Avenue N. W., Room N3647
Washington, DC 20210
Tel: (202) 693-1999

A Guide for Control of Laser Hazards, 4th Edition, Publication #0165
American Conference of Governmental and
Industrial Hygienists (ACGIH)
1330 Kemper Meadow Drive
Cincinnati, OH 45240
Tel: (513) 742-2020
Internet: www.acgih.org/home.htm

Laser Institute of America
13501 Ingenuity Drive, Suite 128
Orlando, FL 32826
Tel: (800) 345-2737
Internet: www.laserinstitute.org

Compliance Engineering
70 Codman Hill Road
Boxborough, MA 01719
Tel: (978) 635-8580

International Electrotechnical Commission
Journal of the European Communities
EN60825-1 TR3 Ed.1.0—Laser Safety Measurement and Instrumentation
IEC-309—Plug, Outlet and Socket Coupler for Industrial Uses
Tel: +41 22-919-0211
Fax: +41 22-919-0300
Internet: http://ftp.iec.c.h/

Cenelec
European Committee for Electrotechnical Standardization
Central Secretariat
rue de Stassart 35
B-1050 Brussels

Document Center
1504 Industrial Way, Unit 9
Belmont, CA 94002-4044
Tel: (415) 591-7600

Equipment and Training

Laser Safety Guide
Laser Institute of America
12424 Research Parkway, Suite 125
Orlando, FL 32826
Tel: (407) 380-1553

Laser Focus World Buyer's Guide
Laser Focus World
Penwell Publishing
10 Tara Blvd., 5th Floor
Nashua, NH 03062
Tel: (603) 891-0123

Lasers and Optronics Buyer's Guide
Lasers and Optronics
Gordon Publications
301 Gibraltar Drive
P.O. Box 650
Morris Plains, NJ 07950-0650
Tel: (973) 292-5100

Photonics Spectra Buyer's Guide
Photonics Spectra
Laurin Publications
Berkshire Common
PO Box 4949
Pittsfield, MA 01202-4949
Tel: (413) 499-0514

Chapter 3 General Description

The *Hurricane i* system includes all of the components necessary to produce ultrashort optical pulses to the milli-Joule level. In addition to the *Mai Tai* seed laser and *Evolution-15* pump laser, other internal components include an optical pulse stretcher, a regenerative amplifier and an optical pulse compressor. Separate system components include the power supplies for the internal pump and seed lasers, as well as the Synchronization and Delay Generator (*SDG II*) that controls the precise timing required for regenerative amplification. The system also includes a notebook computer with Windows®* -based *Hurricane i* control software pre-installed.

Note

User's manuals for the *Mai Tai* and the *Evolution-15* lasers are included with the system and contain detailed descriptions of these systems. Note that the version of the *Mai Tai* used in the *Hurricane i* is not a tunable laser, but is optimized to operate at a single wavelength within a narrow range around 800 nm.

Ti:Sapphire Laser Theory

The Ti^{3+} titanium ion is responsible for the laser action of Ti:sapphire. Ti:sapphire is produced by introducing Ti_2O_3 into a host crystal of Al_2O_3, where Ti^{3+} ions substitute for a small percentage of the Al^{3+} ions. The electronic ground state of the Ti^{3+} ion interacts with the host crystal and is split by lattice vibrations into a pair of very broad levels. Transitions occur from the vibrational levels of the upper electronic state, excited by a blue or green pump laser, to the lower vibrational levels of the ground state.

The possibility of these transitions between broad energy levels results is a wide range of wavelengths over which laser emission may occur. A Ti:sapphire laser can produce light from less than 700 nm to over 1 µm in wavelength—the broadest tuning range of any single laser medium. This extremely broad tuning range or "bandwidth," while not directly utilized in the *Hurricane i* system, has important consequences for producing ultrashort pulses, as described in the section that follows.

The Ti:sapphire crystal exhibits high resistance to thermally induced stress. This resistance allows it to be optically pumped at relatively high average powers without danger of fracture. However, it cannot handle the high peak powers that would result from seeding the amplifier directly with femtosecond pulses. Stretching the pulse prior to amplification and recompressing it following amplification, a technique called Chirped Pulse Amplification (CPA), circumvents this limitation.

**Windows is a trademark of Microsoft Corporation.*

Chirped Pulse Amplification

A bright beam traveling through a Ti:sapphire crystal tends to self-focus. In this effect, intense light modifies the refractive index of a material, causing the light to focus and intensify even further, potentially damaging the material. This tendency makes it necessary to limit the peak power of a pulse in the Ti:sapphire gain material to less than 10 GW/cm^2.

CPA circumvents this obstacle in three steps. The first step stretches a very short seed pulse supplied by a mode-locked femtosecond laser. Stretching the pulse, i.e., increasing its duration, reduces its peak power, which greatly reduces the probability of damage to the Ti:sapphire crystal.

The second step amplifies the stretched pulse by passing it through the excited Ti:sapphire rod. A pump laser sends an excitation pulse to the Ti:sapphire crystal rod just prior to the arrival of the stretched seed pulse, which is then amplified. The third step recompresses the stretched, amplified pulse as close as possible to its original duration.

The fundamental relationship that exists between laser pulse width and bandwidth is that a very short pulse exhibits a broad bandwidth. Therefore a device that can delay certain wavelengths relative to others can, in principle, stretch a short pulse over a longer time. Likewise such a device can compress a long pulse into a shorter one by reversing the procedure. The phenomenon that delays or advances some wavelengths relative to others is called Group Velocity Dispersion (GVD), or less formally, “chirp.”

A pulse is said to have positive GVD, or positive chirp, when the shorter (bluer) wavelengths lead the longer (redder) wavelengths. If the bluer light is delayed more than the redder light, the pulse has negative chirp.

CPA starts by lengthening a low energy, short-duration pulse by as much as 10^4 by using a combination of dispersive optics to form a “pulse stretcher.” The pulse energy is then increased in the Ti:sapphire regenerative amplifier. Finally, a compressor recompresses the pulse to close to its original pulse width. Figure 3-1 illustrates this process.

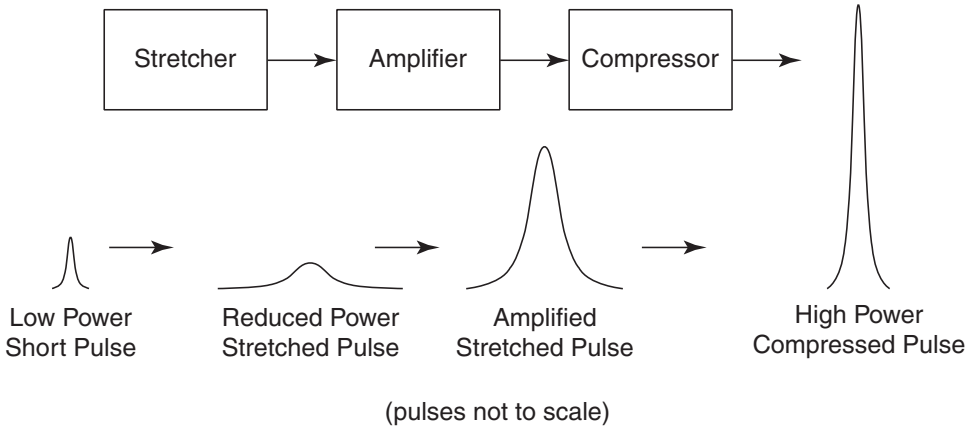


Figure 3-1: Principle of Chirped Pulse Amplification

Pulse Stretching and Compression

Light incident on a diffraction grating experiences dispersion; that is, its component wavelengths—its spectrum—are spatially separated, and so its frequency components are also spatially separated. The dispersed spectrum can be sent through a combination of optics to direct the different frequencies in different directions so that one end of the frequency range travels over a longer path than the other frequencies that are present in the light beam. If the light beam is pulsed, the result of this dispersive design is to lengthen the duration of the pulse, and reduce its peak power.

A prism, which is a simpler optic than a diffraction grating, can also be used for these purposes. However because the pulse passes through a prism, negative GVD is introduced by the glass or quartz of the prism body—that is, blue frequencies are delayed relative to the red frequencies each time the pulse passes through the prism. Gratings are often a better choice for CPA because they simplify the dispersion compensation of the pulse.

The grating and routing mirrors in the stretcher are configured so that the bluer components of the spectrum travel a longer path than the redder components, causing the redder components to exit the stretcher first. In the compressor, the spatially spread beam is flipped so that the redder components have to take the long path, allowing the bluer components to catch up. This compresses the pulse back close to its original width.

Figure 3-2 shows a simplified pulse stretcher. A short pulse is spectrally spread and then, by making one end of the spread pulse travel farther than the other end, the pulse is temporally broadened. The same optical components act as a compressor when the leading component of a temporally stretched pulse is forced to take the longer path, thereby allowing the trailing component to catch up. In the pulse stretcher shown below, the bluer components are forced to take the longer path.

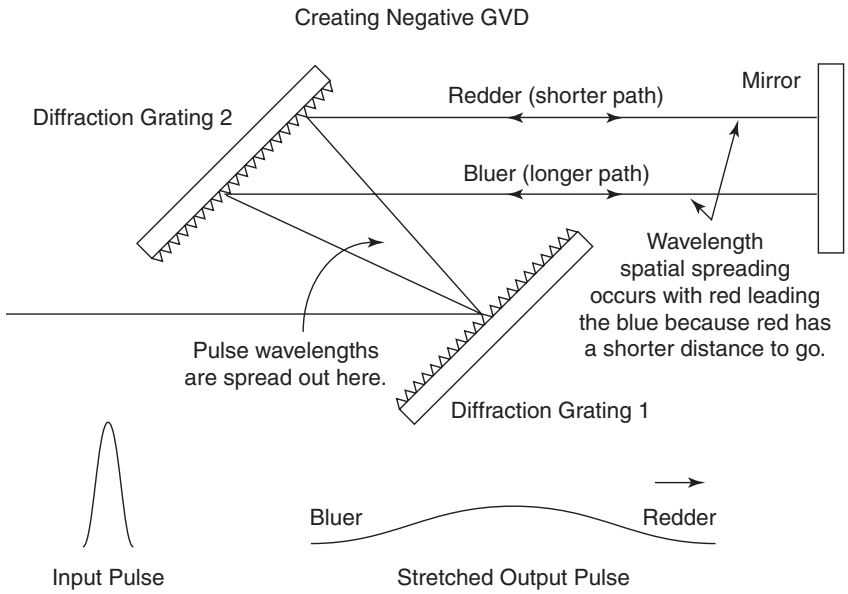


Figure 3-2: Principle of Pulse Stretching Using Negative GVD

The Hurricane i Pulse Stretcher and Compressor

The *Hurricane i* pulse stretcher and compressor make use of some simplifying modifications. A simple but elegant retroreflector assembly reflects the beam back onto a single grating in the stretcher, avoiding the need to precisely align two stretcher gratings. The beam is also multipassed to achieve the required spectrum spread using less complex optics.

The same design principal is used in the compressor, resulting in only two gratings used instead of four, thus simplifying the alignment and maintenance of the system.

The compressor uses a horizontal retroreflector while the retroreflector in the stretcher is vertical. They are used to flip the red and blue components end for end, so that, in the compressor, the bluer wavelengths are now forced to take the longer path. This allows the redder wavelengths to catch up and reduce the pulse duration to close to its original length.

The retroreflector in the compressor is mounted on a track for easy translation along the beam path, which allows for the fine adjustment required to compensate for small routine fluctuations in the dispersion that takes place in the amplifier cavity. Fine adjustment of this retroreflector translation is provided by a dc motor and motion controller.

The property of GVD or chirp for a pulse described above is actually a nonlinear effect, and the chirp contains components that depend upon the higher order powers of the pulse bandwidth. For the *Hurricane i* amplifier, however, these higher order chirp effects are kept to a small enough level so that additional complexity in the optical design is not required.

Pulse Selection and Pockels Cells

Once the pulses leave the stretcher, selecting a pulse for retention in the amplifier cavity is accomplished by using of the polarization of its light. This polarization is controlled by means of Pockels cells in the amplifier cavity. A Pockels cell is an electro-optic device that, without an applied voltage, has essentially no effect on light transmitted through it.

When the proper high voltage is applied, however, the crystalline material in a Pockels cell acts as a ¼ waveplate and rotates the polarization of transmitted light by 45° each time a pulse passes through.

Note

The voltage for the Pockels cells is provided by two high-voltage supplies in the *SDG II* (1 kHz systems) or by a separate power supply (5 kHz systems). The actual drivers for the Pockels cells are in the *Hurricane i* head.

Properly aligning a Pockels cell, even as a passive transmissive optic (i.e., with no applied voltage), is important for it to function properly. Likewise the applied voltage must be calibrated to achieve the precise degree of polarization rotation required.

The input Pockels cell is paired with a passive ¼ waveplate, and the optical path is designed so that the beam makes a double pass through this combi-

nation. A double pass of the beam through a ¼ waveplate rotates the polarization of the pulsed beam by 90°, from horizontal to vertical or vice versa.

When the cell is off, the double pass through the passive ¼ waveplate flips the beam polarization; when the cell is on, the beam experiences a double pass through two ¼ waveplates, leaving its polarization unchanged.

Chapter 4 describes how the input Pockels cell combines with the optics in the amplifier to select a pulse for amplification.

The output Pockels cell works in conjunction with the polarizer in the amplifier cavity to output an amplified pulse at a time determined by the *SDG II*. Details on how the timing is set for ejecting an amplified pulse are provided in "The Synchronization and Delay Generator" later in this chapter.

One measure of the quality of pulse selection is given by the contrast ratio —the factor by which the amplifier output power exceeds the power in spurious pulses that may be present before or after the main, "true" pulse. The value of the contrast ratio is determined by the quality of the ¼ waveplates, the activation time of the Pockels cells (which is a function of their intrinsic birefringence) and their drive electronics.

On-Board Spectrometer

The *Hurricane i* includes an on-board spectrometer that provides near real-time monitoring of the bandwidth at one of two different points within the system.

In addition to the main reflections, or "orders," from the grating surface, gratings also produce dimmer orders that are not used in CPA. The system directs these reflections to a spectrometer using an optical fiber. A fiber connector jumper on the *Hurricane i* connector panel allows the bandwidth of the pulses from either the stretcher or the compressor grating to be monitored.

In normal operation, the spectrometer is used to monitor the bandwidth of the pulses from the compressor grating, i.e., the width of the *Hurricane i* output pulses. During maintenance or troubleshooting, the optical fiber can be moved to sample the bandwidth of the pulses from the stretcher for use as a diagnostic tool.

Regenerative Amplification

The regenerative amplifier can be thought of as a Q-switched, cavity dumped Ti:sapphire laser that is operated as an amplifier. Pulses from the seed laser (that have an energy exceeding the energy of the spontaneous emission in the amplifier) are injected into the amplifier cavity. Instead of amplifying the spontaneous emission that normally happens in a laser, the stimulated emission of the laser rod in a regenerative amplifier amplifies the seed laser pulses.

Note

At times, when aligning the system, the *Hurricane i* is operated as a laser rather than a regenerative amplifier.

Regenerative amplifiers, seeded by low energy laser pulses, are an efficient means of generating very high peak-power pulses. After leaving the stretcher, the *Mai Tai* mode-locked pulses selected for amplification are confined in the amplifier cavity using the polarization discrimination techniques described above. Pulses not selected are diverted from the cavity and "dumped" internally.

The frequency rate of mode-locked pulses from the seed laser is about 80 MHz. Selecting pulses at kilohertz repetition rates for amplification enables the gain in the amplifier to be concentrated on fewer pulses. After achieving the appropriate energy level, the selected pulses are cavity dumped to the compressor, again using polarization discrimination techniques.

Amplification occurs as a seed pulse passes multiple times through the Ti:sapphire rod, which has been excited by the pump beam of the Nd:YLF *Evolution* laser. Typically, an input pulse of only a few nano-Joules of energy can be amplified to roughly a milli-Joule using a single Ti:sapphire rod.

Normally the amplification of the pulse by the Ti:sapphire rod is about 3 or 4 times in a single pass. However, the multiple passes of the regenerative amplifier can result in an energy amplification greater than 10^6 at the output of the compressor. When the compressor restores the short duration of the pulse, the amplified energy results in correspondingly amplified peak power.

The Hurricane i Repetition Rate

The frequency at which the *Hurricane i* produces amplified pulses is set by the repetition rate of the pulses from the *Evolution-15* pump laser. This rate is preset to either 1 kHz or 5 kHz, and should not be changed, because this would affect the thermal equilibrium of the *Hurricane i*. However the *SDG II* allows the *Hurricane i* repetition rate to be reduced without adjusting either the *Evolution-15* or the *Mai Tai* seed laser. The lowest repetition rate available is about 1 Hz. The SDG II itself is described below; specifics about operating the *SDG II* can be found in Chapter 4.

The Synchronization and Delay Generator (SDG II)

The Synchronization and Delay Generator, or *SDG II*, provides the timing needed to synchronize the Pockels cells to capture pulses in the amplifier and to eject them into the compressor. This timing includes synchronization with the *Mai Tai* and *Evolution-15* lasers. An error of only two or three nanoseconds in this synchronization will result in extraneous output pulses that can produce measurement errors or damage to optical components.

As explained above, the input Pockels cell confines the selected pulse in the amplifier. To ensure that only one pulse at a time is admitted for amplification, the input Pockels cell is synchronized to the RF signal generated by the *Mai Tai* mode-locker. The input Pockels cell then transmits the first stretched seed pulse from the mode-locked train that arrives just after a pump pulse has excited the Ti:sapphire rod. The input Pockels cell continues to make this selection after each pump pulse.

An adjustable delay for firing the input Pockels cell is provided, in order to ensure that the cell only fires after the selected pulse has passed completely through it.

The output Pockels cell ejects the amplified pulse into the compressor. Following synchronization with the input Pockels cell, there is an adjustable delay from 0 to 999 ns before activating the output cell to ensure the captured pulse is released at optimum amplification. This delay allows for the time the pulse takes to complete an integral number of round trips of the amplifier cavity.

The *SDG II* is first triggered by a TTL positive-edge pulse provided by the *Evolution-15* laser. It then produces separate triggers with adjustable delays for both Pockels cells. OUT 1 DELAY on the front panel provides the trigger connection to the input Pockels cell; OUT 2 DELAY provides the trigger connection to the output Pockels cell. The delay is adjusted by means of the controls on the front panel, and the corresponding delay is displayed (in nanoseconds) above each control.

OUT 3 DELAY, a third delay, is provided so that the user can synchronize target or monitor devices to the *Hurricane i* output pulse. It might be used, for example, to provide timing control for an oscilloscope display.

The repetition rate of Pockels cell switching (and hence the repetition frequency of the *Hurricane i* output) is dependent on the pre-set repetition rate of the input trigger from the *Evolution-15* laser. The INPUT DIVIDE control provides a means of reducing the *Hurricane i* repetition rate without having to adjust the *Evolution-15* laser. The operation of the *SDG II* is explained in Chapter 4.

The *SDG II* also contains the control and signals for the Bandwidth Detector (BWD). The purpose and operation of the BWD is explained in Chapter 4.

Hurricane i Control Software

Complete control of the *Hurricane i*, including direct control of the *Evolution-15* pump laser and the *Mai Tai* seed laser, is available through the software interface provided with the system. In addition, comprehensive status information as well as on-board diagnostic information is conveniently displayed for the system and its components.

Detailed instructions for each of the functions available through the *Hurricane i* software and user interface are provided in Chapter 6, "Operation."

Performance Specifications

Table 3-1*: Hurricane i* Specifications[1]

Energy per Pulse	
1 kHz	> 1 mJ
5 kHz	> 0.25 mJ
Pulse Width,[2]	< 130 fs
Transform Limit[3]	< 1.5 x transform limit
Energy Stability[4]	< 1% RMS
Wavelength	Preset to one wavelength between 780 nm and 820 nm
Transverse Mode	TEM_{00} (< 1.5 x transform limit)
Beam Diameter at $1/e^2$ points	6 mm, nominal
Beam Pointing Stability[5]	< ± 25 µrad
Contrast Ratio	
Pre-pulse[6]	> 1000:1
Post-pulse	> 100:1
Polarization	Linear, Horizontal
Direct Access to Oscillator Output	> 700 mW, < 100 fs at 800 nm

[1] *Due to our continuous product improvement program, specifications may change without notice.*
[2] *A Gaussian pulse shape (0.70 deconvolution factor) is used to determine the pulse width (FWHM) from an autocorrelation signal as measured with a Spectra-Physics Model SSA autocorrelator.*
[3] *Assuming Gaussian pulse shape*
[4] *RMS with near-Gaussian distribution.*
[5] *Per deg. C (ambient temperature) per hour*
[6] *Specification for pre-pulse contrast ratio for 5 kHz operation is > 500:1*

Chapter 4 Controls, Indicators and Connections

This chapter describes the hardware controls, indicators, and connections available on the *Hurricane i*, the *SGD II* controller, and the dc motor motion controller. It is important to review the information in this chapter before the system is installed.

During normal operation, the system is controlled through the software interface described in Chapter 6, "Operation." It is possible however to operate the *Hurricane i* "manually" by means of the hardware controls described in this chapter. For example, they can be used when installing or troubleshooting the system.

If the system is to be operated manually, it is still recommended that the descriptions and procedures in Chapter 6 first be reviewed, as that chapter contains important information about the control and behavior of the *Hurricane i.*

Hurricane i Assembly External Controls

Output End Panel

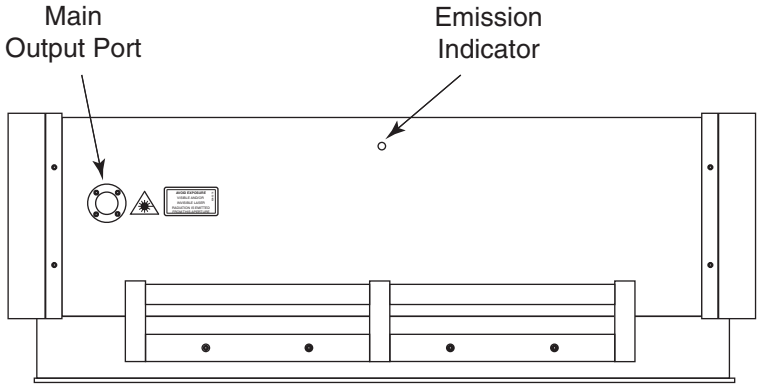


Figure 4-1*:* Front Panel

Main output port—the front exit port for the amplified pulse.

Emission indicator—glows to indicate that the *Evolution-15* is activated, and, therefore, the *Hurricane i* may be producing laser pulses. Note that the indicator glows when the *Evolution-15* is activated, even if the internal shutters in the system are closed.

Output Side Panel

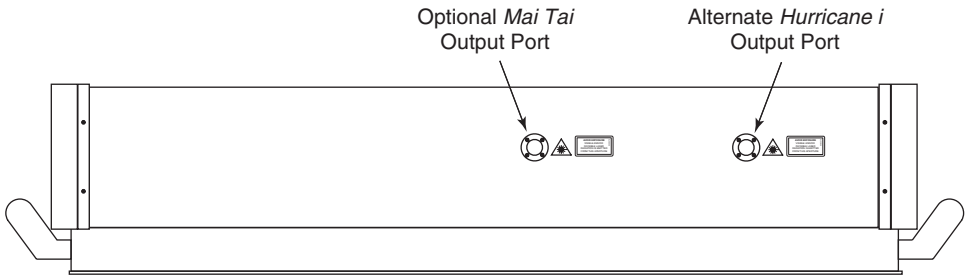


Figure 4-2*:* Output Side Panel

***Mai Tai* output port**—when open, provides access to the seed beam. This port is compatible with standard beam tubes.

To use this optional port:

1. Close the internal shutters in the *Hurricane i*, the *Mai Tai* and the *Evolution-15.*
2. Remove the external cover from the *Mai Tai* port.
3. Install any beam tube(s) to be used.
4. If the normal *Hurricane i* output ports are not to be used, either do not activate the *Evolution-15* pump laser or be sure to cover both *Hurricane i* output ports.
5. Open the *Mai Tai* shutter to allow the seed beam to exit the *Mai Tai* port. (A small fraction of the *Mai Tai* beam may exit the *Hurricane i* port if it is uncovered and the *Hurricane i* shutter is open.)
6. Open the shutters of the *Evolution-15* and *Hurricane i* if the amplified output is to be used simultaneously with the seed beam.

Alternate output port—alternate port for the *Hurricane i* amplified pulse.

To use this side port:

1. Close the internal shutters in the *Hurricane i*, the *Mai Tai,* and the *Evolution-15.*
2. Close the front output port.
3. Remove the *Hurricane i* cover.

The cover interlock on the *Hurricane i* **does not** deactivate the *Mai Tai* laser. When the *Hurricane i* cover is removed and the *Mai Tai* shutter is open, be extremely careful to avoid exposure to the *Mai Tai* laser beam.

4. Remove the M_7 turning mirror and mount (used to turn the beam out of the main output port, see Figure 7-1).
5. Remove the external cover from the side output port.
6. Install any beam tube(s) to be used.
7. Replace the *Hurricane i* cover.
8. Open the internal shutters of the *Evolution-15,* the *Mai Tai,* and the *Hurricane i* to resume operation.

Rear (Umbilical) Panel

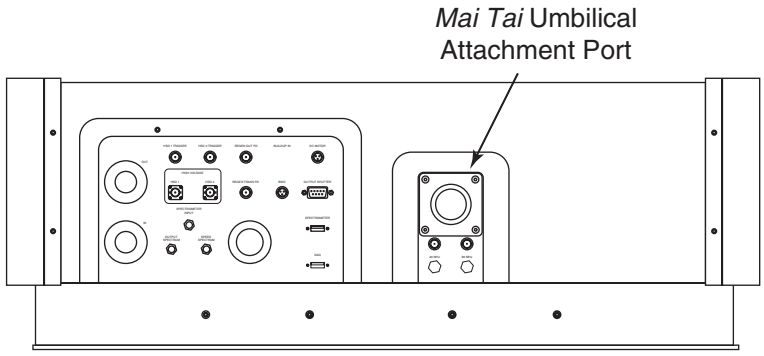


Figure 4-3*:* Umbilical Panel, *Hurricane i*

Note

Allow a minimum of 8 in. clearance in front of the umbilical panel to allow the proper bend radius for the *Mai Tai* umbilical. This is a requirement for the fiber-optic cables within the umbilical that supply optical power from the *Mai Tai* power supply to the seed laser.

Note that the *Evolution-15* umbilical cable passes through the opening in this panel and is hard-wired to the internal *Evolution-15* laser head.

HIGH VOLTAGE HSD 1 connector (MHV)—connects by means of a high-voltage cable to the 1–6 kV dc H.V. 1 output connector on the back of the *SDG II* (1 kHz systems) or to the auxiliary power supply (5 kHz systems) for driving the input Pockels cell.

HIGH VOLTAGE HSD 2 connector (MHV)—connects by means of a high-voltage cable to the 1–6 kVdc H.V. 2 output connector on the back of the *SDG II* (1 kHz systems) or to the auxiliary power supply (5 kHz systems) for driving the output Pockels cell.

HSD 1 TRIG connector (BNC)—connects to the OUT 1 DELAY connector on the front of the *SDG II* for triggering the input Pockels cell.

HSD 2 TRIG connector (BNC)—connects to the OUT 2 DELAY connector on the front of the *SDG II* for triggering the output Pockels cell.

IN connector—the input water connection for the chiller.

OUT connector—the output water connection for the chiller.

DC MOTOR input connector (BNC)—connects to the motor controller (provided with the system). This provides control of the micrometer motor that sets the length of the compressor. Refer to "Motor Controller" below.

REGEN OUT PD (BNC)—provides connection to the detector used to monitor the amplified pulse exiting the regenerative amplifier

REGEN TRANS PD (BNC)—provides connection to the detector used to monitor the amplified pulse train in the regenerative amplifier cavity.

BUILDUP IN connector—reserved (labeled D/A IN on some units).

SPECTROMETER connector (USB)—connects the output of the spectrometer to the control computer.

OUTPUT SHUTTER connector (**USB**)—provides computer control of the *Hurricane i* shutter located in the compressor.

SPECTROMETER INPUT fiber-optic connector (**SMA**)—connects via a fiber-optic jumper cable to either the OUTPUT SPECTRUM connector to monitor the output of the *Hurricane i*, or to the SEED SPECTRUM connector to monitor the output of the *Mai Tai* seed laser.

OUTPUT SPECTRUM fiber-optic connector (**SMA**)—links the spectrometer to the detector for monitoring the reflection from the compressor grating and, thus, the bandwidth of the amplified pulse before compression.

SEED SPECTRUM fiber-optic connector (**SMA**)—links the spectrometer to the detector for monitoring the reflection from the stretcher grating and, thus, the bandwidth of the seed pulse before stretching and amplification.

DAQ connector (**USB**)—connects the computer to the data acquisition unit.

BWD connector—is a 4-pin connector (3 pins are used) that connects to the BWD connector on the back of the *SDG II*.

***Mai Tai* Umbilical Port**—is the connection for *Mai Tai* control and power, including the fiber optics for the diode laser pump source for the *Mai Tai*. This is the standard *Mai Tai* umbilical connection (refer to the *Mai Tai User's Manual*). It is accessed through a space in the *Hurricane i* panel.

40 MHz Output—connects by means of a BNC cable to the RF SYNC connector on the back of the *SDG II* to synchronize the capture of the mode-locked seed pulses.

80 MHz Output—not used in the *Hurricane i* system.

The Synchronous Delay Generator (SDG II)

During normal operation, the *Hurricane i* is controlled by means of the software interface (see Chapter 6). It is possible, however, to use the manual controls available on the system to control the amplified output.

The *SDG II* controls the selection of pulses from the *Mai Tai* and the repetition rate of the pulsed output of the *Hurricane i*. First, it acts as a counter that selects mode-locked seed pump pulses at either the 1 kHz or the 5 kHz amplifier rate. The SDG II synchronizes the Mai Tai pulses with the Evolution pump laser; that is, it captures the next seed pulse while the laser rod is still excited by the pump pulse. It does this by providing an adjustable delay, in nanoseconds, that is used to set the input Pockels cell of the amplifier to capture the pulse.

The second adjustable delay controls the output Pockels cell to eject the pulse into the compressor after it has been amplified. The *SDG II* allows the output repetition rate to be reduced from its pre-set value by dividing the input synchronization signal from the *Evolution* pump laser by integers.

The third adjustable delay provides a trigger for laboratory equipment, such as the horizontal sweep of a high-speed oscilloscope.

The *SDG II* also contains high-voltage supplies to power the drivers for the Pockels cells in systems that operate at 1 kHz. The drivers themselves are located in the *Hurricane i* below the regenerative amplifier cavity.

Front Panel

Figure 4-4: *SDG II* Front Panel

TRIGGER FREQUENCY display—shows the output frequency set for the *Hurricane i*, in kHz.

INPUT DIVIDE control—allows the output frequency of the *SDG II* to be reduced by integer divisors (e.g., ÷2, ÷3, etc.). This allows the output pulse rate of the *Hurricane i* to be changed without changing the repetition rate of either the *Evolution* or *Mai Tai*, which might affect amplifier stability.

The largest factor available corresponds to a 1 Hz repetition rate (i.e., ÷1000 for a 1 kHz system; ÷5000 for a 5 kHz system). The reduction factor is not shown, only the actual output frequency is displayed.

SYNC ENABLE control—selects synchronized (LED is on) or unsynchronized (LED is off) mode. If both the LED and error lamp are on, the sync source is absent or the *Mai Tai* has stopped mode-locking. Cycle the SYNC ENABLE button after correcting the error condition. The *Hurricane i* will not operate correctly in unsynchronized mode.

Synchronized mode allows the sync outputs to fire based on the current pump laser delay setting (OUT 1 DELAY) and the next available seed pulse. Essentially, it provides a way to fire the *Hurricane i* input Pockels cell based on sync signals from two different circuits: the *Evolution* Q-switch signal and the *Mai Tai* pulse train.

SYNC ERROR indicator—when this lamp is on and the *SDG II* is in synchronized mode, either the sync signal is absent or the *Mai Tai* laser has stopped mode-locking.

BWD (PD1, PD2 and RESET controls)—see the "Bandwidth Detector" section below.

MODE control—this button selects CONTINUOUS repetition rate firing (based on the input trigger) or SINGLE SHOT firing. The selected mode is indicated the corresponding LED.

MAN TRIG control—when the selected MODE is SINGLE SHOT, pressing this button causes the three output triggers to fire a single pulse.

ENABLE controls—these three buttons turn on and off the three adjustable output trigger signals. If a signal is enabled (ON), its corresponding LED is on. When set to OFF, that output is deactivated and the other outputs remain active.

OUT 1 DELAY display, control and connector—the display shows the selected delay, from 0 to 1275 ns, between the time the Q-switch in the *Evolution* laser is fired and the time the input Pockels cell is turned on to capture the current seed pulse in the *Hurricane i* amplifier. The output is a 1.5 µs positive TTL pulse.

The control knob adjusts the delay in 250 ps increments, or 10 ns increments if the knob is pushed in during adjustment. The BNC connector connects to the *Hurricane i* HSD 1 TRIG connector and provides a low-voltage sync signal for the high-voltage driver that turns on the input Pockels cell to capture the current seed pulse.

OUT 2 DELAY display, control and connector—the display shows the selected delay, from 0 to 1275 ns, when the output Pockels cell is turned on to eject the amplified pulse into the compressor. The output is a 1.5 µs positive TTL pulse.

The control knob works the same way as the one for OUT 1 DELAY. The BNC connector attaches to the *Hurricane i* HSD 2 TRIG connector to turn on the output Pockels cell in order to eject the amplified pulse.

SYNC OUT DELAY display, control and connector—the display shows the selected delay, from 0 to 1275 ns, when the user can send a trigger signal to an oscilloscope or similar device. The control knob works the same way as the one for OUT 1 DELAY. This delay is synchronized to, but independent of, OUT 1 DELAY and OUT 2 DELAY. The output is a 1.5 µs positive TTL pulse.

Bandwidth Detector

The bandwidth detector (BWD) protects the regenerative amplifier optics from damage caused if the stretcher cannot adequately reduce the peak power of the *Mai Tai* pulses before they are amplified. For example, this problem could result from blocking a portion of the beam in the stretcher.

The BWD relies on the signals from two fast photo detectors placed behind the tall stretcher end mirror (Figure 4-5). This mirror transmits about 5% of the incident light to the detectors. If the signal from either detector falls below a threshold (set for each version of the *Hurricane i)*, the BWD is activated.

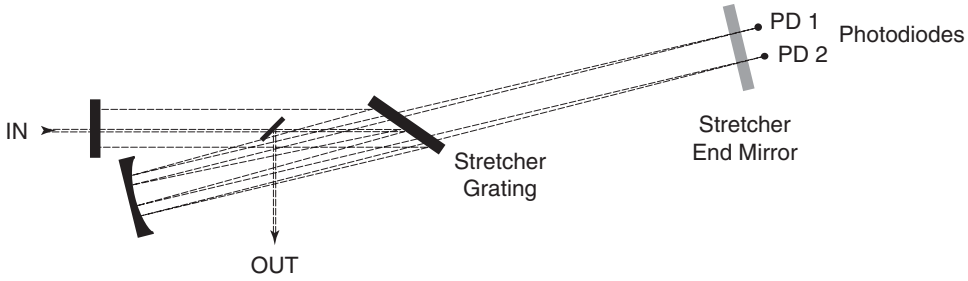


Figure 4-5: Optical Design of the BWD

When the seed laser is stable and properly mode-locked, the BWD permits the *SDG II* to function normally. When the BWD senses a lack of signal, a relay will disable the trigger signal that fires the Pockels cells. No pulses are selected for amplification, thus protecting the optical components.

The following indicators and connectors for the BWD are on the *SDG II*:

PD 1, PD 2 indicators (front panel)—when both lamps are on, they indicate that the stretcher is spreading the seed pulse spectrum properly on the tall stretcher end mirror. PD 1 represents the red end of the spectrum; PD 2 represents the blue end. If a lamp is off, the corresponding photo detector is receiving a signal below threshold.

RESET button (front panel)—when the underlying problem is resolved and both lamps are on, pressing this button resets the relay and restores the outputs from OUT 1 DELAY and OUT 2 DELAY.

BWD connector (front panel)—this 4-pin 12 mm connector connects to the BWD photodiodes via the 9-pin D-sub connector on the *Hurricane i* umbilical panel.

BWD ON switch (back panel)—this switch, when in the *down* position, disables the BWD and allows the amplifier to function regardless of spectrum spread or the detection of a BWD signal. Use this switch for troubleshooting purposes only.

Warning!

The BWD is not a fail-safe device. Its purpose is to protect against the restriction of the stretched pulse spectrum. It cannot detect instabilities in the seed spectrum itself that result from poor modelocking. Optical damage to the system can result from such instabilities. Disabling the BWD can result in permanent damage to the *Hurricane i*.

Back Panel

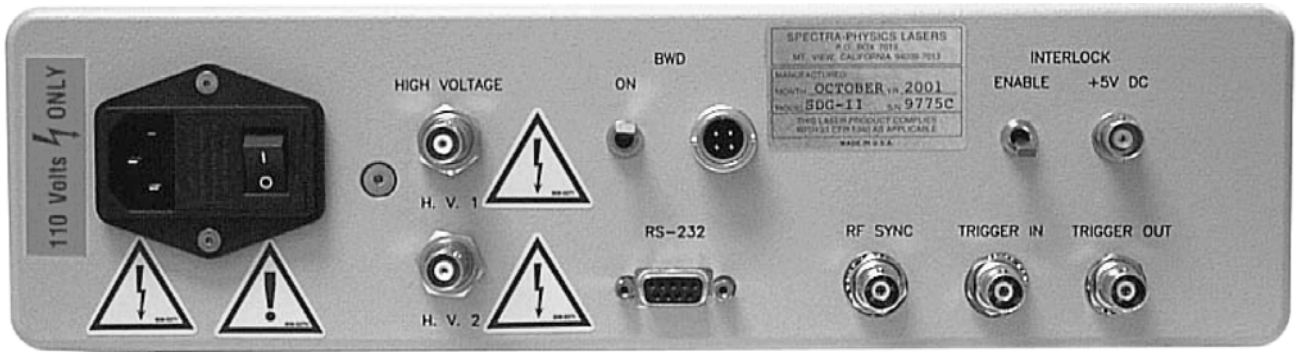


Figure 4-6: ***SDG II*** **Back Panel**

Power connector and switch—provide ac input power for the *SDG II* (110/220 Vac). The unit includes EMI protection, a ½ amp fuse, and an on/off (I/0) switch.

HIGH VOLTAGE (HV1, HV2) connectors—provide 1–6 kV dc output, connected by means of high-voltage cables to the HSD1 and HSD2 connections for the Pockels cells on the *Hurricane i* umbilical panel (used on 1 kHz systems only).

Note

Systems that operate at a 5 kHz repetition rate use a separate high-voltage power supply to drive the Pockels cells. The HV1 and HV2 connectors on the *SDG II* are not used on these systems. Keep these outputs capped when the auxiliary high-voltage power supply is used.

BWD ON switch—see "Bandwidth Detector" above.

BWD connector—see "Bandwidth Detector" above.

RS-232 connector (serial port)—allows computer control of the *SDG II*.

Refer to Chapter 6, "Operation," for information on computer control of the system.

RF SYNC connector—attaches to the 40 MHz *Mai Tai* output connector (see Figure 4-3) by means of a high-speed cable to synchronize capture of the seed pulse in the amplifier. Jitter is specified at < 250 ps.

TRIGGER IN connector—accepts TTL-compatible, 0–50 kHz input from the SYNC OUT connector on the front panel of the *Evolution* power supply.

TRIGGER OUT connector—provides a 200 ns fixed output trigger signal. The input pulse trigger to the *SDG II* produces this TRIGGER OUT signal before it is sent to the three adjustable outputs on the front panel.

INTERLOCK ENABLE switch—enables or disables the +5V DC connector. When the switch is *up*, the connector is functional, and the center pin of the BNC is grounded. When the switch is *down*, the connector is disabled.

+5V DC connector (input)—accepts an input signal from a safety interlock switch; for example, a switch that senses when the laboratory door has opened. If this connector is enabled and the safety interlock switch opens, OUT 1 DELAY and OUT 2 DELAY will be disabled.

Warning!

The use of the +5V DC connector as a safety switch will *not* disable the *Evolution* or *Mai Tai* lasers. These lasers have their own safety interlocks. Please refer to their specific manuals.

Motion Controller

The motion controller provides translation of the horizontal retro-reflector assembly in the compressor. This movement changes the length of the beam path in the compressor, which provides the fine adjustment needed to compensate for small changes in the dispersion that take place in the amplifier cavity.

The controller connects to the DC MOTOR BNC connector on the *Hurricane i* umbilical panel. The controller can be either battery powered or used with the DC adapter provided.

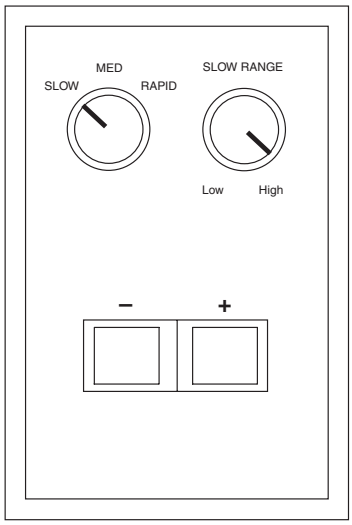


Figure 4-7: Motion Controller

SLOW/MED/HIGH control—sets the coarse speed range at which the motor micrometer moves when either the "+" or "–" buttons are pushed.

SLOW RANGE control—provides either LOW or HIGH fine control of the SLOW speed of the motor micrometer.

+ button—moves the compressor retro-reflector to lengthen the beam path in the compressor

– button—moves the compressor retro-reflector to shorten the beam path in the compressor

Chapter 5 Installation

Installation of the *Hurricane i* system must be performed by an authorized service representative. This service is included as part of your purchase agreement. Please call to arrange an appointment. The customer will be held responsible for any damage to the equipment that results from unauthorized installation, and such action may also void the warranty.

Please read this chapter thoroughly and become familiar with the procedures and safety precautions before the system is installed. You may also unpack the laser and locate it in the area where it will be used. Refer to "Unpacking and Inspection" at the beginning of this manual.

Warning!

Do not attempt to install the laser yourself. Unauthorized installation will void the warranty.

Requirements for Installation

Before the *Hurricane i* system is installed, select a suitable location. Ensure that sufficient utilities are available and diagnostic equipment is present.

Location

The *Hurricane i* must be located on an optical table with minimum space of about 4 ft. x 3 ft (1.2 m x 0.9 m). Allow a minimum of 8 in. (21 cm) of clearance in front of the *Hurricane i* umbilical panel. It is highly recommended that this table be located in an environment that is free of dust, oils and drafts.

Caution!

The *Hurricane i* assembly weighs about 400 lbs (182 kg). Be certain the its selected location can provide stable support.

The *Hurricane i* is designed to tolerate temperature fluctuations by actively controlling the temperature of each individual module (e.g., *Mai Tai*, *Evolution*, and regenerative amplifier). However, the best performance will be achieved if the room temperature does not fluctuate by more than ±2º C.

The *Hurricane i* should be placed in a location that allows easy access, because some adjustments may be required to optimize performance.

Required Utilities

The *Hurricane i* requires the utilities listed below. More details are given in the *Mai Tai* and *Evolution* user manuals, which are shipped with this product.

US and Japan

- two separate B-type outlets, (110 ±10) Vac, 50/60 Hz, 15 A for the power supplies
- one separate B-type outlet, (110 ±10) Vac, 60 Hz, 15 A for the chiller
- a standard B-type 115 Vac socket capable of providing 5 A

Europe

- two separate F-type outlets, (220 ±20) Vac, 50 Hz, 8 A for the power supplies
- one separate F-type outlet, (220 ±20) Vac, 50 Hz, 8 A for the chiller
- a standard F-type 220 Vac socket capable of providing 3 A

Recommended Diagnostic Equipment

The following equipment is recommended for day-to-day operation of the *Hurricane i* and should be available at the time of installation:

- a power meter capable of measuring from 10 mW to 20 W average power between 527 nm and 900 nm (e.g., Spectra-Physics 407A)
- a fast CRT analog oscilloscope capable of 300 MHz or better (e.g., Tektronix 2467, 7104 or TDS 3052)
- a fast photodiode with a 2 ns rise time or better (e.g., Electro-Optics Technology Model ET 2000)
- IR viewer and IR card
- an autocorrelator (e.g., Spectra-Physics SSA)

Evolution-15 Power Supply

Refer to the *Evolution-15 User's Manual* for physical specifications and procedures on preparing for installation.

Mai Tai Power Supply

Refer to the *Mai Tai User's Manual* for physical specifications and procedures on preparing for installation.

Interconnection Diagram

Figure 5-1 and Figure 5-2 are schematics of the signal connections and control connections, respectively, between components of the *Hurricane i* system. For simplicity, water hoses and the more obvious electrical connections (e.g., power to the computer) are not shown.

Also not shown is the fiber-optic jumper that connects the spectrometer to either the input from the stretcher or the compressor. Refer to the description of the rear (umbilical) panel of the *Hurricane i* assembly in Chapter 4 for information about this jumper.

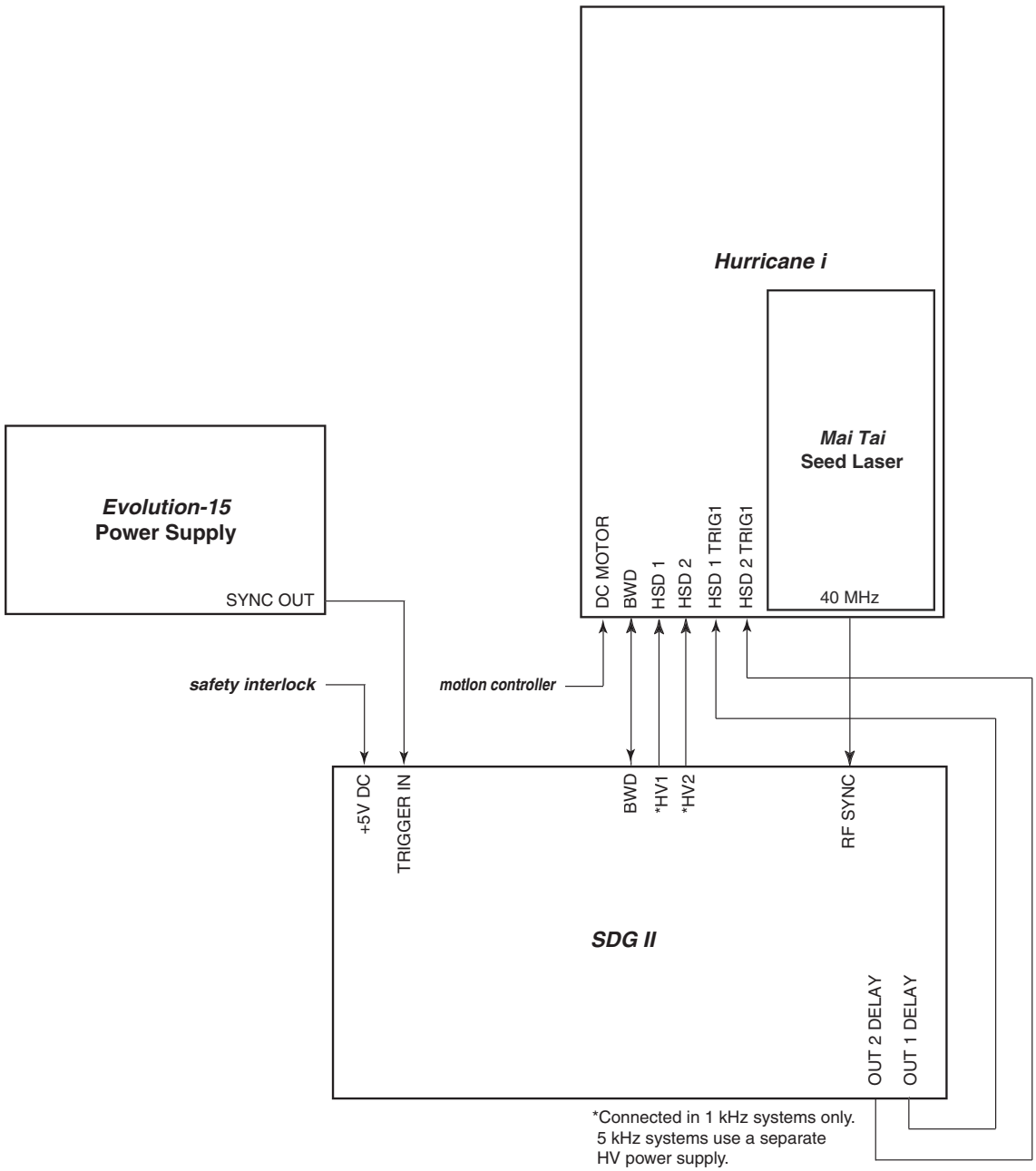


Figure 5-1: Interconnect Diagram, 1 kHz, *Hurricane i*

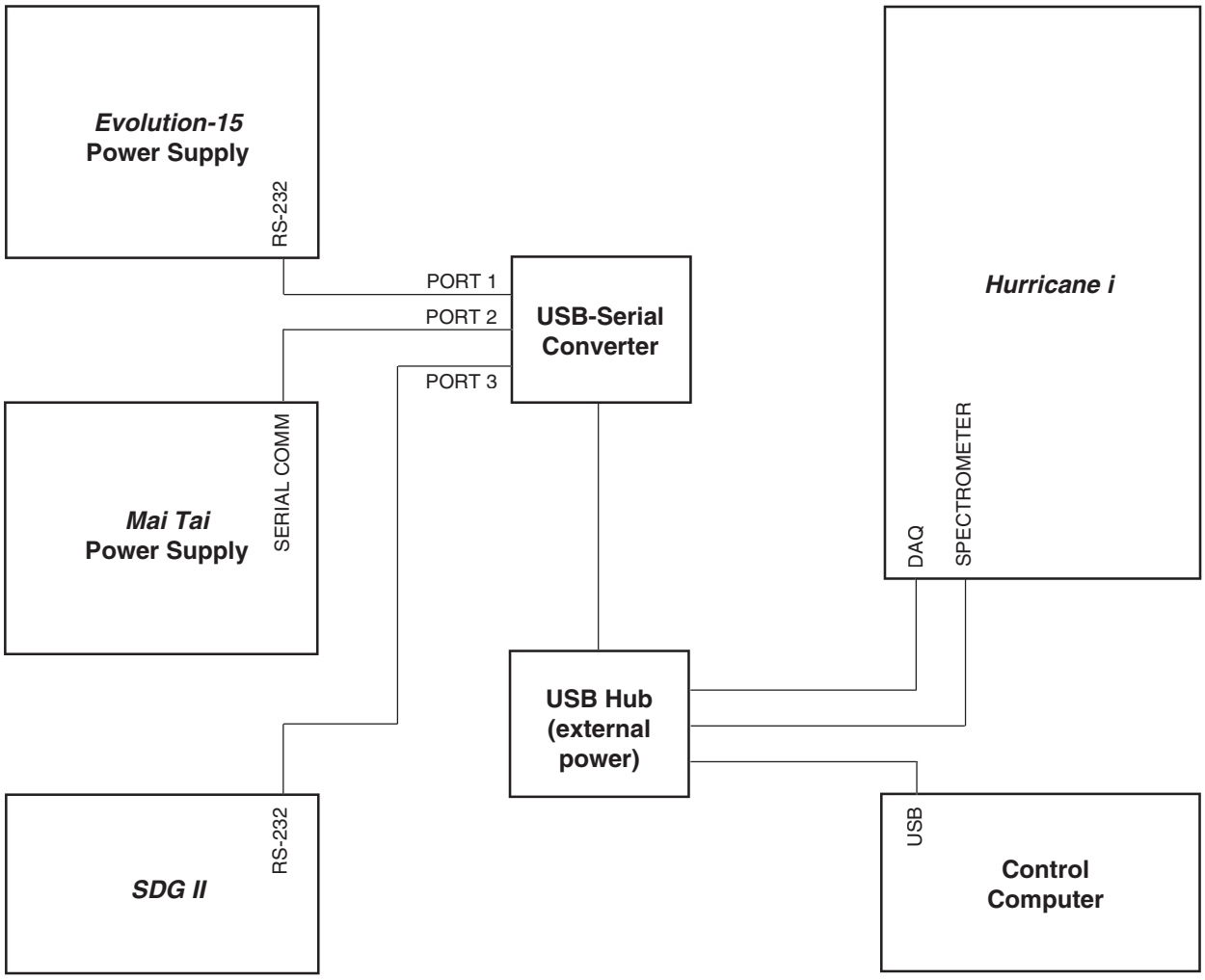


Figure 5-2: *Hurricane i* Control Diagram

Chiller

The Ti:sapphire amplifier rod absorbs heat from the *Evolution-15* pump beam and from its own amplified, circulating beam and must be cooled to avoid damage.

The water flow to the amplifier is in series downstream from the *Mai Tai* as shown in Figure 5-3. Water from the chiller is connected to the IN port of the *Hurricane i* connection panel and goes directly to the *Evolution-15*. Before cooling the pump laser, however, a tee divides the cooling water flow to a parallel path into the *Mai Tai*.

It is important to the performance of the seed laser that its cooling water be kept at a constant 21°C. The exhausted cooling water from the *Mai Tai* still has sufficient heat removal capacity to cool the regenerative amplifier rod.

This design takes the place of the connections described in the manuals for the *Mai Tai* and *Evolution-15* lasers. Note that any hose connections that might be present in the *Mai Tai* umbilical are not used in the *Hurricane i*, and should be set aside (left unconnected).

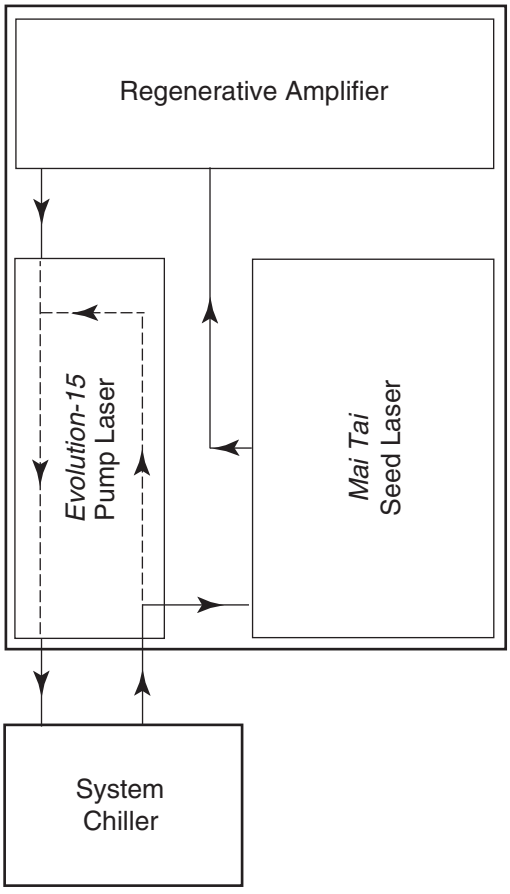


Figure 5-3: Flow Diagram for Chiller Water

Mechanical Specifications

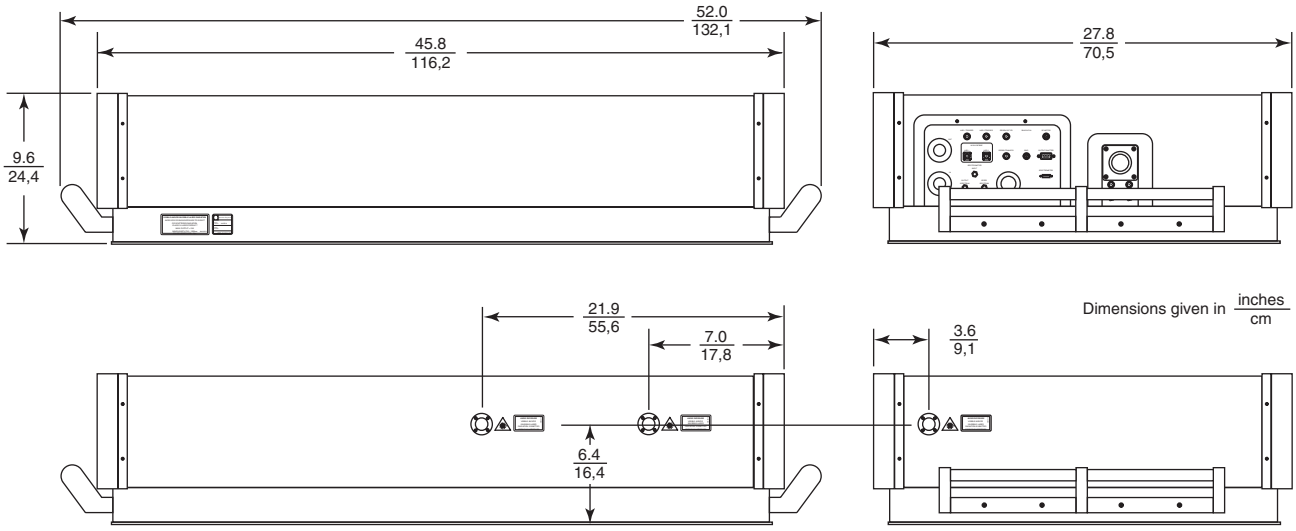


Figure 5-4: Outline Drawing, *Hurricane i*

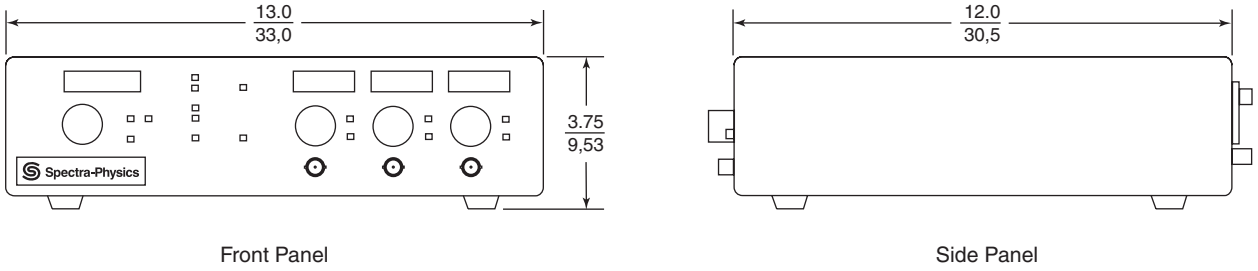


Figure 5-5: *SDG II* Outline Drawing

Table 5-1: Physical Specifications for *Hurricane i*

Weight	434 lb	197 kg
Length	45.8 in	116.2 cm
Width	27.8 in	70.5 cm
Height	9.6 in	24.4 cm

Chapter 6 Operation

The following procedures will result in laser emission from the *Hurricane i* output port. Ensure that all persons in the room are wearing adequate eye protection. Safety glasses rated at OD4 or greater for all lasing wavelengths present in the system must be worn at all times when operating the *Hurricane i*. Also ensure that the anticipated beam is safely terminated.

It is recommended that the following equipment be kept on hand:

- a power meter capable of measuring between 10 mW and 20 W of average power from 527 nm to 900 nm (e.g., Spectra-Physics 407A)
- a fast CRT analog oscilloscope capable of 300 MHz or better (e.g., Tektronix 2467, 7104 or TDS 3052)
- a fast photodiode with a 2 ns rise time or better (e.g., Electro-Optics Technology Model ET 2000)
- IR viewer and IR card
- an autocorrelator (e.g., Spectra-Physics SSA)

This chapter contains procedures for starting, stopping and operating the *Hurricane i* system. Familiarize yourself with the functions available through the software interface before attempting to use the system.

Do not “click on” a function or change a parameter through the software interface without first understanding the action. Note that many functions are reserved for service or factory personnel. Unauthorized use of these functions may damage your system and void your warranty.

Verify that all connectors are plugged into the *Mai Tai* power supply (they should never be disconnected—if they are, refer to Chapters 4 and 5 for information on reconnecting them).

Verify the chiller reservoir has been filled to the correct level. Verify it is set to 21° C.

Warning!

AC line voltage to the crystal heater circuit in the *Evolution-15* power supply is always present when the power supply is plugged in, even when the ac switch is off. The chiller must be left on while the power supply is connected to mains voltage or permanent damage will result to the LBO doubling crystal in the *Evolution-15.*

Startup Procedure

Read through this entire procedure before performing it for the first time. Note that the component lasers, as well as the *Hurricane i* system itself, need time to warm up in order to achieve stable operation.

1. The chiller should already be on and stable at 21°C.
2. Start the *Mai Tai* power supply warm-up sequence.
   a. Turn on the power supply ac switch.
   b. Turn on the power supply key switch. A sequence of messages described in the *Mai Tai User's Manual*, will appear on the LCD display on the power supply, followed by a series of boot tests. After completing the boot tests, the LCD display will read:

      "Success. Boot test passed."

      The LCD screen will now display a four-line message, similar to:

MAITAI
MODE : IR Power
Pump power : 4.650W
Warmup : 90%

   c. Wait for the warm-up percentage to reach 100%. The *Mai Tai* power supply will take about 15 to 30 minutes to warm-up completely. If the *Hurricane i* control computer is not turned on, do so now, but do not start the *Hurricane i* control program yet.

      When the power supply warm-up is complete, the LCD screen will switch to a display of status codes.
3. Start the *Evolution-15* power supply.
   a. Verify that the LBO heater control temperature is at the proper factory-set temperature.
   b. Turn on power supply ac switch.
   c, Turn on the power supply key switch.
4. Turn on the power to the *SDG II*.
5. Start the *Hurricane i* control program. Once the Main Screen is available, the procedure to start the *Hurricane i* system will proceed from the leftmost panel ("Mai Tai") to the rightmost ("Regen").
6. Start the *Mai Tai* seed laser.
   a. Click on and hold down the START button for about 3 seconds until the EMISSION indicator turns on. The laser is on when the EMISSION indicator is on. Initial power, however, will be very low as indicated on the display.
   b. After the *Mai Tai* has achieved maximum output power, verify the MODELOCKED indicator is on. If it is not on, refer to the procedures in Chapter 8, "Troubleshooting," to investigate the status of the *Mai Tai* laser.

c. Click on OPEN SHUTTER. When the SHUTTER indicator turns on, the shutter will open and emission from the *Mai Tai* will be present in the *Hurricane i* cavity.

For systems with a *Hurricane i* shutter: if the system was properly shut down, the *Hurricane i* shutter should be closed at this time. Whenever the *Mai Tai* laser is on, even if other components are off, it is possible for a small amount of light to be emitted from the *Hurricane i*. Check the *Hurricane i* shutter status using the tab that activates the SDG panel on the lower half of the display,

7. Click on START on the Evolution control panel.

   Note that, unlike the *Mai Tai*, the *Evolution-15* does not require its start button to be "held down." There is a ramp-up time of 5 to 10 seconds before the *Evolution-15* begins laser emission.

8. Once the *Mai Tai* and *Evolution* have ramped up to their appropriate output powers, allow 15 to 30 minutes for the system to warm up.

9. Start the *Hurricane i* amplifier.

   a. Click on the SDG panel tab on the lower half of the display.

   b. The OUTPUT SHUTTER should be closed.

   c. Click on RESET for the BWD interlock. If the *Mai Tai* is properly mode-locked, the indicators for both BWD1 and BWD2 will be lit. Refer to the procedures in Chapter 8, "Troubleshooting," if the indicators do not come on.

   d. Click on START on the REGEN control panel.

      At this point, the REG EMISSION indicator should come on and the *Hurricane i* should begin producing amplified pulses. The OUT 1 and OUT 2 indicators should be illuminated on the REGEN panel of the display and on the *SDG II* controller itself.

   e. Move the REGEN interface control switch from SET to READ.

10. Open the OUTPUT SHUTTER.

The *Hurricane i* should now be producing output with performance close to that recorded at the time of its last shutdown. If this is not the case, proceed to the section below titled "Optimizing Pulsed Output."

Shutdown Procedure

Before shutting down, record in a system log the output power of the *Hurricane i*, along with the level of the *Mai Tai* seed laser, the *Evolution-15* pump laser and the timing parameters of the *SGD II*.

1. If the READ/SET control is set to READ, Click on STOP on the Regen panel to stop the amplifier from amplifying pulses.

   When the READ/SET control is in SET mode, clicking on STOP will cause the READ/SET control to change to READ mode, and clicking STOP again will then turn off the production of amplified pulses.
2. Click on STOP on the *Evolution* panel to turn off the *Evolution-15*.
3. Turn off the *Mai Tai* by clicking on STOP on the *Mai Tai* panel.
4. Shut down the *Hurricane i* control software and turn off the host computer if appropriate.
5. Turn off the *SDG II*.
6. Turn off the key switch and the ac power to the *Evolution-15* power supply.

   Note that the heater circuit for the doubling crystal in the *Evolution-15* remains on.
7. Turn off the key switch and the ac power to the *Mai Tai* power supply.
8. Leave the chiller on unless the system is not going to be used for a long time (several days).

Optimizing Pulsed Output

Temperature changes or similar variations in the environment of the *Hurricane i* may necessitate an adjustment to optimize the pulsed output.

Optimizing Peak Power

When the *Hurricane i* output has been selected to exit from the front panel, the PEAK POWER MONITOR displayed on either the SDG panel or the SPECT panel can be used to optimize the power of the individual output pulses. Adjust the compressor length using the MOTOR CONTROL (which displays relative values only) to achieve the highest value on the PEAK POWER MONITOR display.

Optimizing Pulse Compression

The compressed pulse should look like that in Figure 6-1.

To achieve the shortest pulse, view the compressed pulsed using an autocorrelator. The shortest pulse is achieved using the motor controller, which optimizes the compressor length by changing the position of the horizontal retro-reflector.

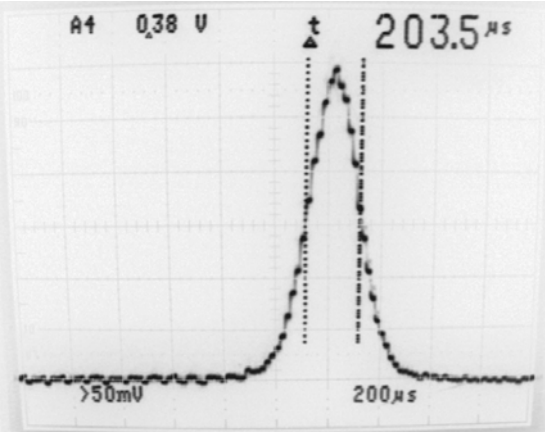


Figure 6-1: Typical Autocorrelation of a Well-Compressed Pulse

A quick method to optimize the compressor length is by observing the pulsed output on a white business card. When the compressor length is correct, the high peak power of pulse will cause the beam to appear blue in the center due to frequency doubling on the card.

Warning!

The peak power of a typical system pulse is insufficient to ignite common types of paper; nevertheless, always use caution when inserting any material into the beam. Be certain that any reflections from the inserted object are directed downwards.

Beam Profile

Beam uniformity is best checked by means of visual inspection of the pattern made on paper containing a fluorescent dye, such as a business card. This simple method gives excellent results when properly used. Refer to the warning above before inserting anything into the beam.

A poor beam often indicates optical damage or misalignment, most likely misalignment of the pump beam. Refer to the troubleshooting guide in Chapter 8 if a poor beam is suspected.

Control Software

The control software for the *Hurricane i* is accessed using a Windows*® shortcut found in the Programs folder of the START menu and also on the desktop. The latest version of the software is always available from Spectra-Physics. This section describes version 1.0.7.

Main Screen

The three upper panels on the main screen (Figure 6-2) provide controls for the *Mai Tai* seed laser, the *Evolution-15* pump laser and the regenerative amplifier (regen). The display and functions in the bottom panel change with each tab selection. These panels are described in detail in this chapter.

Warning!

The *Hurricane i* software includes controls intended for use only by authorized Spectra-Physics personnel who are trained in their operation. These controls are so identified in this chapter; do not use them.

Figure 6-2: *Hurricane i* Main Screen

*Windows is a registered trademark of Microsoft Corporation

Mai Tai Panel

START button—starts the seed laser. This button must be "held down" for about 3 seconds to activate the *Mai Tai*.

STOP button—stops operation of the seed laser and closes the *Mai Tai* shutter.

MAI TAI EMISSION indicator—illuminates when the seed laser output is available, although there may be no emission if the *Mai Tai* shutter is closed.

INTERLOCK—is reserved for future use.

OPEN SHUTTER button—opens or closes the internal shutter in the *Mai Tai*.

SHUTTER indicator—illuminates when the *Mai Tai* shutter is open.

POWER indicator—displays output power in Watts (bar indicator) and as a relative value (digital display).

MODELOCKED indicator—indicates that the *Mai Tai* is producing mode-locked seed pulses.

Evolution Panel

START button—starts the *Evolution-15* pump laser.

When START is selected, the diode laser arrays are activated and the EVOLUTION EMISSION indicator turns on. The diode laser arrays begin a controlled ramp-up. After a delay of 5 to 10 seconds, during which a tone sounds, the *Evolution-15* begins lasing.

STOP button—stops operation of the *Evolution-15* pump laser.

EVOLUTION EMISSION indicator—illuminates when current is supplied to the diode lasers that pump the *Evolution-15*.

INTERLOCK indicator—turns on when the remote interlock connected to the back of the *Evolution-15* power supply has been activated (e.g., when the laboratory door opens). The *Evolution-15* will shut down, turning off the amplified output from the *Hurricane i*, when this indicator comes on.

This interlock provides 5 Vdc at 250 mA.

CURRENT SET [A] control—sets the output current (in Amps) of the diode lasers that pump the *Evolution-15,* up to the maximum set point. The new value can be entered directly or adjusted in 0.1 A increments.

CURRENT MONITOR [A] indicator—displays the current (in Amps) of the diode pump laser arrays in the *Evolution-15*.

Note

The current for the *Evolution-15* diode laser arrays was set at the factory to achieve optimum performance of the *Hurricane i* system. This control is provided in the field for troubleshooting or service only — do not change this value unless instructed to do so.

Regen Panel

START button—starts operation of the regenerative amplifier. If all other controls have been properly set, and there are no active interlocks, the *Hurricane i* will start producing amplified pulses when this button is selected.

STOP button—stops operation of the regenerative amplifier when the READ/SET control is in READ mode. See the READ/SET control description below.

REGEN EMISSION indicator—illuminates when the amplified output is available, although if the *Hurricane i* shutter is closed there will be no emission.

Note

The internal shutter used to block the amplified *Hurricane i* output is controlled through the panel activated by selecting the SDG tab on the lower half of the Main screen.

INTERLOCK indicator—illuminates when the BWD circuit has tripped and, thus, needs to be reset.

OUT 1 control—corresponds to the OUT 1 DELAY control on the *SDG II*. It synchronizes the firing of the input Pockels cell (to capture the current seed pulse) with the firing of the Q-switch in the *Evolution-15* laser.

OUT 2 control—corresponds to the OUT 2 DELAY control on the *SDG II*. It synchronizes the firing of the output Pockels cell to eject the amplified seed pulse with the firing of the Q-switch in the *Evolution-15* laser.

SYNC OUT control—corresponds to the SYNC OUT DELAY control on the *SDG II*. It turns on/off the delay between the firing of the output Pockels cell and the transmission of a trigger pulse for use by a laboratory instrument.

DELAY 1 [NS] control—sets the OUT 1 delay from 0 to 1275 ns.

DELAY 2 [NS] control—sets the OUT 2 delay from 0 to 1275 ns.

DELAY 3 [NS] control—sets the SYNC OUT delay from 0 to 1275 ns.

READ/SET control—determines whether the values for synchronous delays of the *SDG II* are controlled by software or by the *SDG II* unit itself.

When READ is selected, the software reads and displays values that have been set on the *SDG II*.

When SET is selected, the software can change the *SDG II* values using input from the entry fields listed above.

When the READ is selected, clicking STOP will cause the OUT 1 and OUT 2 controls to turn off, thereby stopping the emission of amplified pulses from the *Hurricane i*. (Note that the system may still emit light from the *Mai Tai* laser.)

When SET is selected, clicking STOP will cause the OUT 1 and OUT 2 controls to change to READ mode. Clicking STOP again will then turn off the production of amplified pulses.

EV SYSTEM Panel

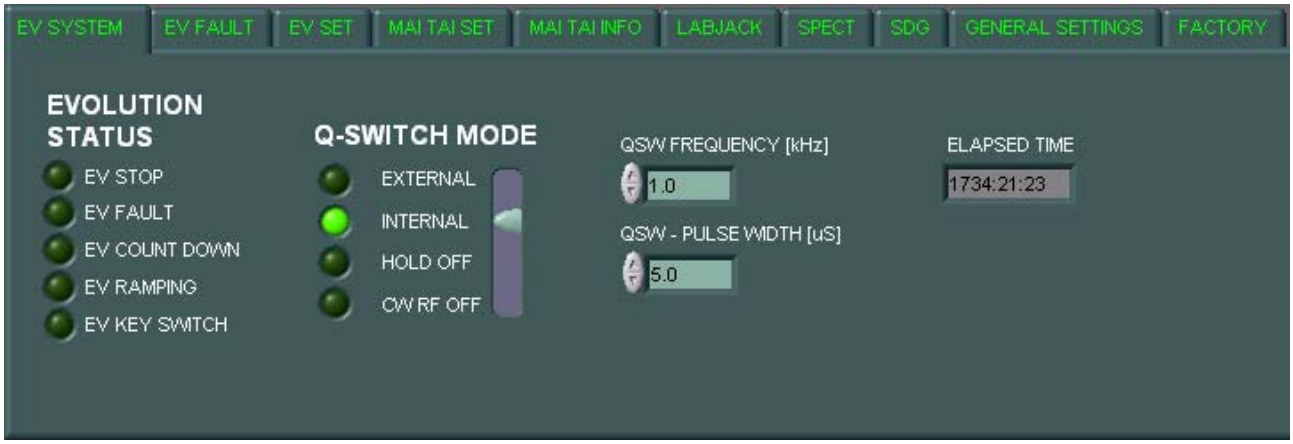


Figure 6-3: The Evolution System Panel

EV STOP indicator—illuminates when the *Evolution-15* is in the STOP state (the pump diode lasers are turned off and the internal shutter is closed).

EV FAULT indicator—illuminates when there is a problem with the *Evolution-15*. Select the EV FAULT tab to display more information.

EV COUNTDOWN indicator—illuminates when the *Evolution-15* has been started and the 5-second countdown to the start of lasing is underway; it turns off when lasing begins.

EV RAMPING indicator—illuminates when the *Evolution-15* is started and the diode lasers are performing their ramp-up; it turns off when the selected diode laser current is achieved.

EV KEY SWITCH indicator—shows the state of the access control key. In normal operation, this indicator is OFF. ON means the key is in the off position; FLASHING means the key switch must be recycled to reset a Fault State.

Q-SWITCH MODE control—sets the mode of the *Evolution-15* Q-switch driver. Do not change these settings unless instructed to do so by Spectra-Physics.

EXTERNAL indicator—this mode is not used for the *Hurricane i.*

INTERNAL indicator—denotes the normal *Hurricane i* operating state for the *Evolution-15*, i.e., the Q-switch trigger source is the internal SAB clock, the Q-switch repetition rate is set by the software, and RF power is being supplied to the AOM transducers to produce Q-switched pulsed output.

HOLD OFF indicator—this mode is used during service.

CW RF OFF indicator—this mode is used during service.

QSW FREQUENCY [KHZ]—sets the frequency of the internal Q-switch trigger source. Note that the *Hurricane i* is optimized for one frequency rate and this value should not be changed unless instructed to do so by Spectra-Physics.

QSW–PULSEWIDTH [µS] control—sets the width of the internal trigger pulse to the Q-switch driver. This value should be 5.0 µs for 1 kHz operation.

ELAPSED TIME indicator—shows the cumulative time the *Evolution-15* laser has been on.

EV FAULT Panel

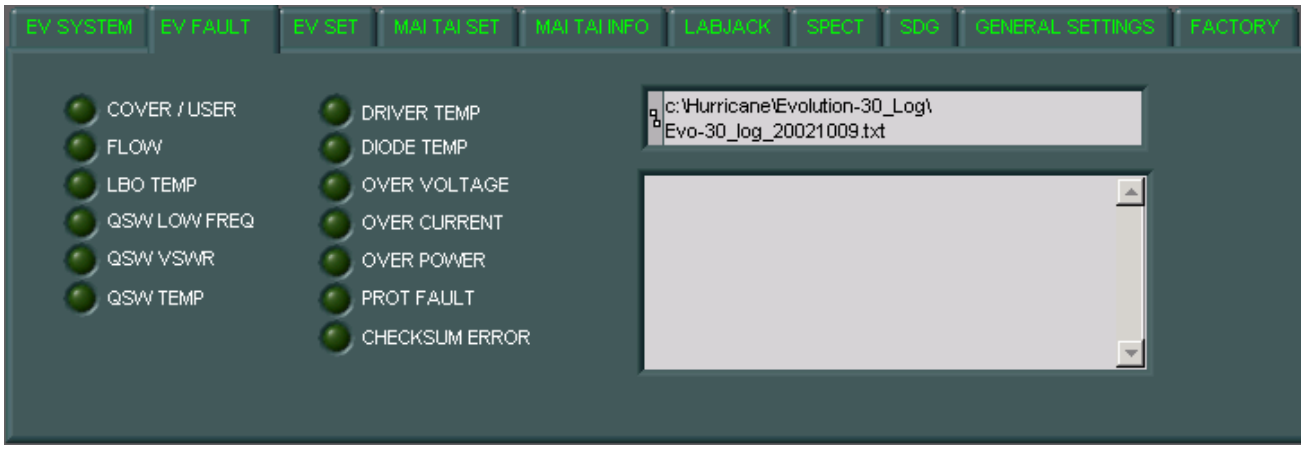


Figure 6-4: The EV Fault Panel

The following indicators are primarily for use by service personnel. Some types of faults however can be cleared by the user. Refer to Chapter 8.

COVER/USER indicator—denotes either

a the remote interlock that connects to the rear of the *Evolution-15* power supply has been activated, or

b during service of the system, one or more of the micro-switches under the cover of the *Evolution-15* head have been activated.

FLOW indicator—illuminates when chiller water flow is less than 2.0 GPM.

LBO TEMP indicator—illuminates when the LBO temperature is outside a preset range around the factory set point.

QSW LOW FREQ indicator—illuminates when the QSW MODE is set to EXTERNAL and the external trigger source drops below 500 Hz.

QSW VSWR indicator—illuminates when one or both of the QSW RF connectors on the back of the *Evolution-15* power supply are disconnected.

QSW TEMP indicator—illuminates when the thermal sensor in either AOM exceeds the safe operating temperature for that device.

DRIVER TEMP indicator—illuminates when the diode laser driver (FET) heatsink becomes overheated due to inadequate airflow to the driver, or to a shorted or over-current condition.

DIODE TEMP indicator—illuminates when the temperature sensor mounted in the laser pump chamber exceeds the safe operating maximum.

OVER VOLTAGE indicator—illuminates when the voltage required to supply the requested current to the diode lasers exceeds the factory-set limit.

OVER CURRENT indicator—illuminates when the current requested to drive the diode laser array exceeds the factory-set limit.

OVER POWER indicator—illuminates when the internal drive FET exceeds the factory-set power limit.

PROT FAULT indicator—illuminates when the internal drive FET protection circuit is activated. **This is a serious internal driver failure that requires repair.**

Warning!

Do not operate the *Evolution-15* if a PROT FAULT error occurs!

CHECKSUM ERROR indicator—illuminates when a garbled message is detected between the control software and the *Evolution-15*.

Log window—displays all the fault conditions, fault corrections and their time stamps. A new file is created each time the *Hurricane i* control program is started. The file name is a time stamp of the first entry written to it: YYYYMMDD.txt.

MAI TAI SET Panel

Figure 6-5: The Mai Tai Set Panel

The *Hurricane i* system provides the option for using the output of the *Mai Tai* as a separate laser. Refer to Chapter 4, "Controls, Indicators, and Connections," for instructions on how to access the *Mai Tai* output. The controls and read-outs provided on this panel and the following panel, MAI TAI INFO, can be used to control and monitor the *Mai Tai* output.

For a detailed description of the *Mai Tai* control functions, consult the *Mai Tai User's Manual* provided with the system. The following is a brief summary of the *Mai Tai* control functions.

Caution!

These parameters are set in the factory to optimize the performance of the *Hurricane i*. **Do not change these settings** without first consulting with your Spectra-Physics representative.

MODE switch—changes the *Mai Tai* between power control and current control. The default setting is power control; the current control mode is for service and troubleshooting. **Do not change this setting** from power control unless instructed to do so by an authorized Spectra-Physics representative.

MODE READING indicator—displays the selected mode.

PUMP POWER control—sets the power level of the pump laser inside the *Mai Tai*. This setting has been set at the factory to optimize the output of the *Mai Tai*. **Do not change this setting** unless instructed to do so by an authorized Spectra-Physics representative.

Note that this power may change to a different, pre-set optimized level if the *Mai Tai* output is set to a different wavelength.

ACTUAL POWER indicator—displays the actual output power level of the pump laser that is inside the *Mai Tai*.

% CURRENT SET control—sets the current level of the *Mai Tai* pump laser as a percentage of the factory pre-set value of its range of operating current. **Do not change this value** unless instructed to do so by an authorized Spectra-Physics representative.

Note that this setting may change to a different, pre-set optimized value if the *Mai Tai* output is set to a different wavelength.

ACTUAL CURRENT indicator—displays actual current level of the *Mai Tai* pump laser as a percentage of its operating range. Current is related to pump output power, and the current required to maintain a given output level will increase over time as the diode lasers for the pump laser age.

WAVELENGTH SET control—changes the *Mai Tai* output wavelength. Refer to the *Mai Tai User's Manual* for the *Mai Tai* tuning range. The wavelength should always be set to 800 nm when the *Mai Tai* is operating as the seed laser for the *Hurricane i*.

WAVELENGTH READ indicator—displays the actual *Mai Tai* operating wavelength. This reading should always be 800 nm (or close to it) when the *Mai Tai* is operating as the seed laser for the *Hurricane i*.

RF PHASE SET control—sets the timing of the RF driver for the mode-locker. This setting has been set at the factory to optimize the *Mai Tai* output. **Do not change this value** unless instructed to do so by an authorized Spectra-Physics representative.

Note that this setting may automatically change to a different, pre-set optimized value if the *Mai Tai* wavelength is changed.

RF PHASE READ indicator—displays the timing of the RF driver for the *Mai Tai* mode-locker.

MODELOCKER ENABLE switch—enables or disables modelocking. Modelocking must be enabled when the *Mai Tai* is operating as the seed laser for the *Hurricane i*.

MODELOCKER indicator—illuminates if modelocking is enabled.

MAI TAI INFO Panel

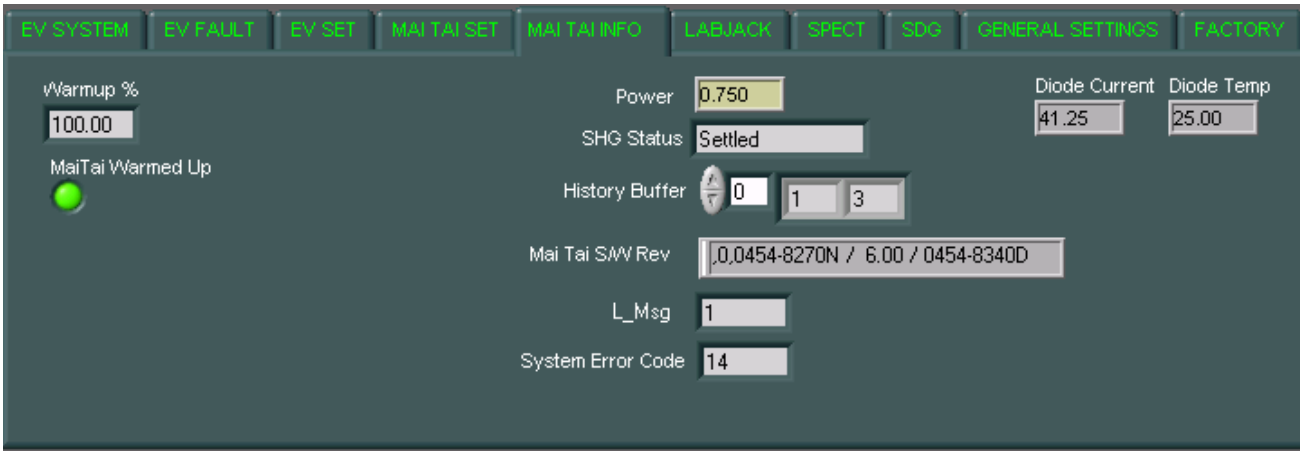


Figure 6-6: The Mai Tai Info Panel

WARMUP % display—shows the percentage of warm-up time elapsed.

MAI TAI WARMED UP indicator—illuminates when the *Mai Tai* is 100% warmed up.

POWER display—shows the average *Mai Tai* output power in Watts.

SHG STATUS display—shows the status of the temperature of the doubling crystal in the *Mai Tai* pump laser. It reads "Settled" when the crystal has stabilized at its operation level.

HISTORY BUFFER display—lists the entries of the history buffer, which can be navigated by clicking the up/down arrows.

MAI TAI SW REV display—identifies the current *Mai Tai* software revision.

L_MSG display—shows the most recent outstanding system message. This is provided for use in troubleshooting by a service technician.

SYSTEM ERROR CODE display—shows the most recent outstanding system error. This is provided for use in troubleshooting by a service technician.

DIODE CURRENT display—shows the actual current reading in Amps for the diode lasers in the *Mai Tai* pump laser. This current is related to pump output power, and the current required to maintain a given output level will increase as the diode lasers age.

DIODE TEMP display—shows the diode laser temperature in degrees Centigrade.

SPECT Panel

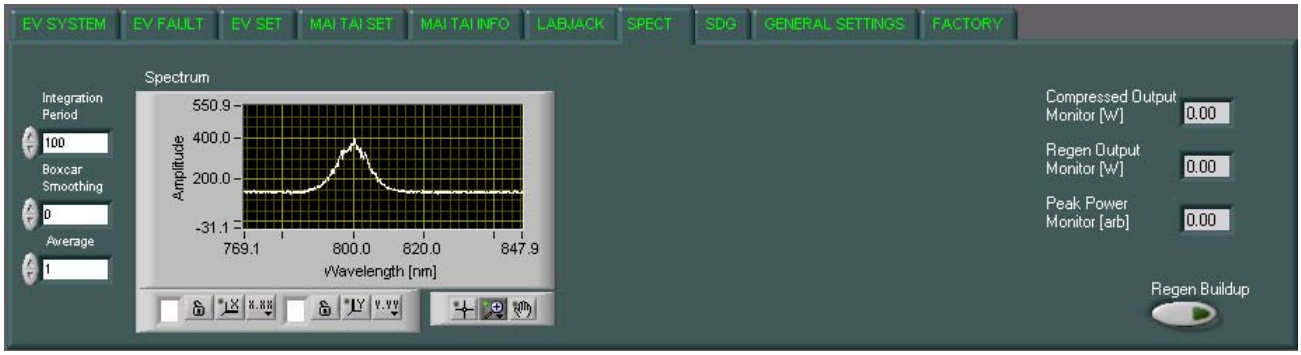


Figure 6-7: The Spectrometer Panel

The spectrometer panel is used to monitor the bandwidth of the pulses entering either the compressor (normal operation) or the stretcher (service operation). Instructions for changing between compressor measurements and stretcher measurements are given in Chapter 4. (Refer to SPECTROMETER INPUT, OUTPUT SPECTRUM and SEED SPECTRUM in the "Back Panel" section starting on page 4-7). This screen provides controls for the spectrometer and displays the results of its measurements.

For detailed information about the operation of the spectrometer, consult the manual from *Ocean Optics* provided with the system.

INTEGRATION PERIOD control—sets the length of time in milliseconds over which the spectrometer integrates the selected input signal. The integration period can be set from 3 to 65,0000; the recommended (default) value is 100 milliseconds.

BOXCAR SMOOTHING display—sets the number of points over which to average the spectrometer data. The range is from 0 to 500; the recommended (default) value is 0.

COMPRESSED OUTPUT MONITOR [W] display—shows the *Hurricane i* average output power. This is a calibrated measurement.

REGEN OUTPUT MONITOR [W] display—shows the regenerative amplifier average output power before it is compressed. This is a calibrated measurement.

PEAK POWER MONITOR [ARB] display—shows an uncalibrated signal that is proportional to the peak power of the *Hurricane i* pulsed output. This display provides feedback to the user while optimizing the *Hurricane i* output using the compressor length motor control.

Note

The PEAK POWER MONITOR is only available when the *Hurricane i* output is directed out through the front panel.

Software control of the compressor length is provided on the SDG panel. To optimize the compressor while viewing the spectrometer display, use the manual control box for the dc motor.

REGEN BUILDUP control—reserved. Do not change this setting.

SDG Panel

Figure 6-8: The SDG Panel

The READ/SET control on the Regen panel of the Main screen determines whether the values for *SDG II* functions are set by software or by the hardware controls on the *SDG II* unit itself. Refer to the description of the functions of the Regen panel earlier in this chapter for a explanation of the interaction of the software and the *SGD II*.

BWD1 indicator—illuminates when photodiode PD 1, used for the long wavelength end of the seed pulse spectrum, is functioning and detecting a pulse.

BWD2 indicator—illuminates when photodiode PD 2, used for the short wavelength end of the seed pulse spectrum, is functioning and detecting a pulse.

When the seed laser is stable and properly mode-locked, BWD1 and BWD2 together permit the *SDG II* to function normally. When either BWD1 or BWD2 senses a lack of signal, a relay will disable the Pockels cells. When this happens, no pulses are selected for amplification, thus protecting the optical components.

BWD OVERRIDE indicator—indicates that the BWD has been disabled, thereby allowing the amplifier to function regardless of spectrum spread.

Warning!

Disabling the BWD can cause permanent damage to the *Hurricane i*.

DC INTERLOCK indicator—reserved for future use.

BWD RESET button—resets the relay for the Pockels cells and allows the *Hurricane i* to resume amplification. Do this after restoring the seed laser spectrum to its proper bandwidth. Note that BWD RESET must be selected during the turn-on sequence in order for the *Hurricane i* to function.

TRIGGER/CONTINUOUS switch—when set to TRIGGER, enables the *Hurricane i* to fire a single pulse by clicking on the S.S. button. CONTINUOUS is the standard operating mode in which the *Hurricane i* produces amplified pulses at a selected repetition rate.

S.S. button—when pressed, causes the *Hurricane i* to fire a single pulse when the TRIGGER mode has been selected.

RF SYNC button—enables the Pockels cells to fire based on the OUT 1 DELAY setting and the next available seed pulse. Essentially, it provides a way to fire the *Hurricane i* input Pockels cell based on sync signals from two different circuits: the *Evolution-15* Q-switch signal and the *Mai Tai* pulse train.

REP RATE DIVIDE control—reduces the basic *Hurricane i* pulse repetition rate by an integer value. It provides the same function as the INPUT DIVIDE control on the *SDG II* itself.

OUTPUT SHUTTER button—opens or closes the shutter between the regenerative amplifier and the compressor. Closing the shutter blocks the *Hurricane i* output pulses.

(Note that on some models, a system may have had its shutter removed and replaced by a different component.)

SHUTTER OPEN indicator—illuminates when the shutter is open. This indicator also illuminates when the shutter has been disconnected.

MOTOR CONTROL—controls the translation of the horizontal retroreflector assembly in the compressor to compensate for the small changes in the dispersion that takes place in the amplifier cavity. The best compensation will be achieved when the PEAK POWER MONITOR indicates an optimum value.

FWD—forward direction of translation of the retroreflector

REV—reverse direction of translation of the retroreflector

FAST/SLOW—changes the speed of the translation

PEAK POWER MONITOR [ARB]—displays an uncalibrated signal that is proportional to the peak power of the *Hurricane i* pulsed output. This is the same display that appears on the Spectrometer panel, and is copied here so that it can be monitored while adjusting the compressor length.

Note

The PEAK POWER MONITOR is only available when the *Hurricane i* output is directed out through the front panel.

GENERAL SETTINGS Panel

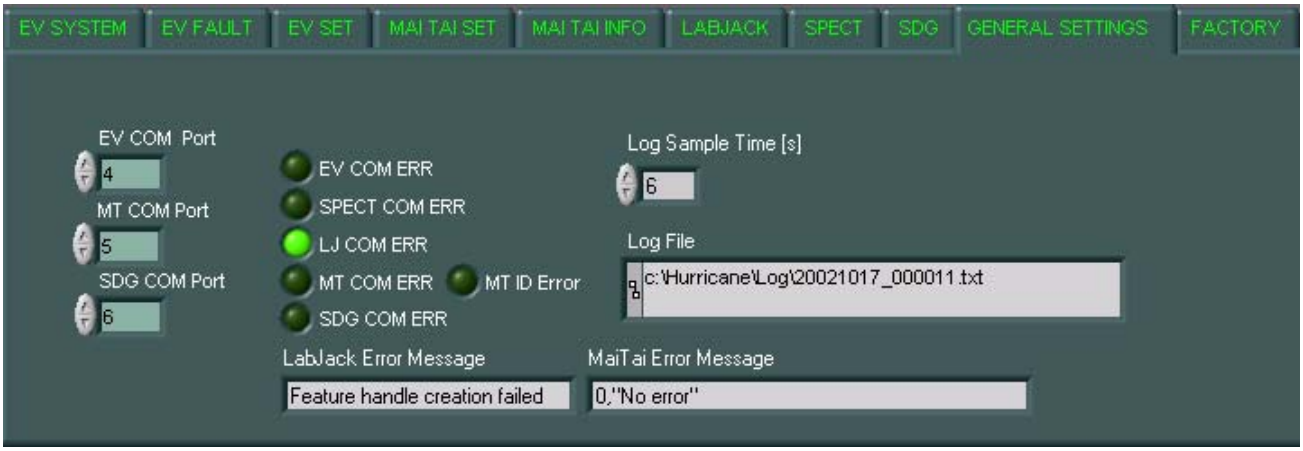


Figure 6-9: The General Settings Panel

The following displays provide settings for the communications ports for the computer to control the indicated subsystem.

EV COM PORT—default value is set at the factory.

MT COM PORT—default value is set at the factory.

SDG COM PORT—default value is set at the factory

When lit, the following indicators signal a communications error with the corresponding subsystem, e.g., a cable is unplugged, a subsystem is turned off. Verify the cables are properly connected (refer to the Interconnect Diagram in Chapter 4) and that the subsystem is turned on appropriately. For additional assistance, contact your Spectra-Physics representative.

EV COM ERR—*Evolution-15* error.

SPECT COM ERR—spectrometer error.

LJ COM ERR—LabJack error.

MT COM ERR—*Mai Tai* error.

SDG COM ERR—*SDG II* error.

MT ID ERR—*Mai Tai* initialization error. The software did not receive a proper response to a query about the software revision. The is for use in troubleshooting by a trained technician.

LABJACK ERROR MESSAGE display—shows the LabJack error messages intended for use by Spectra-Physics service personnel.

LOG SAMPLE TIME[S] control—sets the interval (in seconds) for writing entries to the log file.

LOG FILE display—shows the path and file name for the event log. A new log file is created every time the control program is started. The file name is the time stamp of the first entry written to it: YYYYMMDD_HHMMSS.

MAI TAI ERROR MESSAGE display—shows the most recent outstanding *Mai Tai* error and code for use by Spectra-Physics service personnel.

Warning!

The controls available under the following tabs are reserved for use by trained and authorized Spectra-Physics personnel. Do not use them!

EV SET Panel

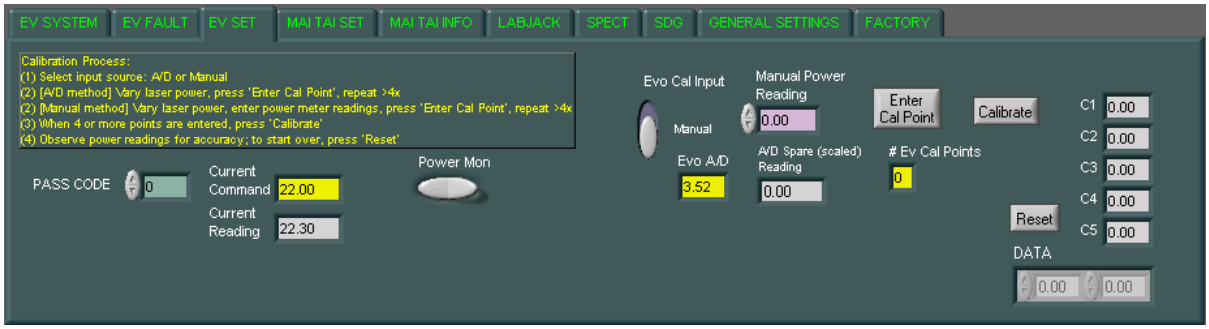


Figure 6-10: The EV Set Panel

LABJACK Panel

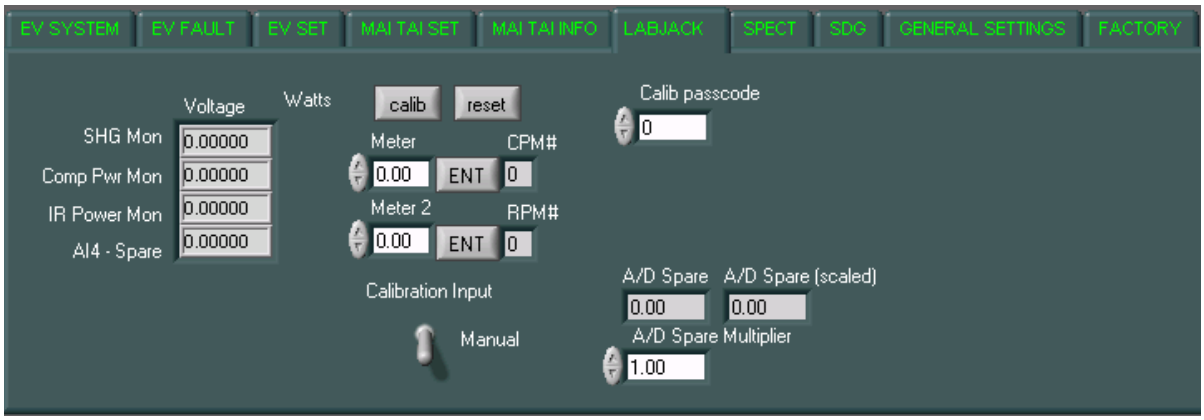


Figure 6-11: the LabJack Panel

FACTORY Panel

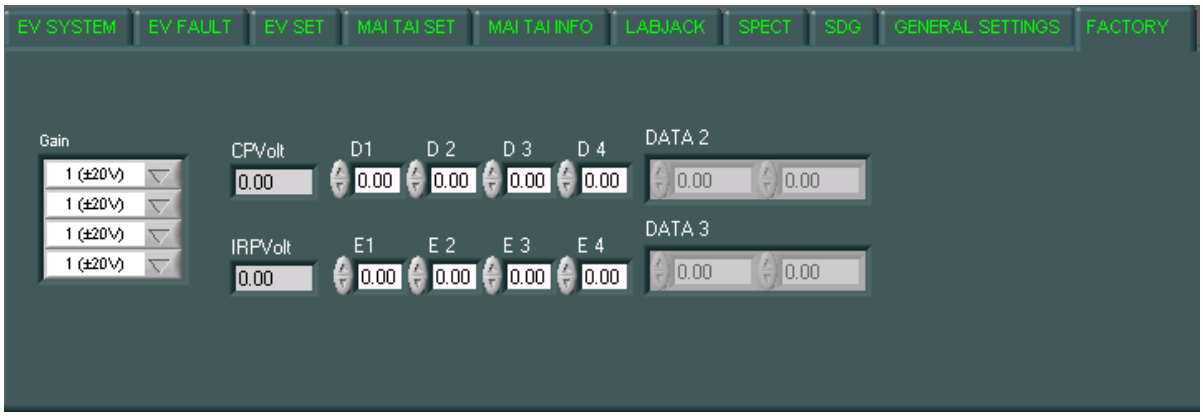


Figure 6-12: The Factory Panel

Chapter 7 Optical Layout

The Hurricane i Beam Path

The *Hurricane i* is designed to be low-maintenance and trouble-free. It is, however, a very sophisticated opto-electrical system. Any maintenance and troubleshooting that may be needed requires an understanding of the beam path and internal adjustments inside the *Hurricane i*.

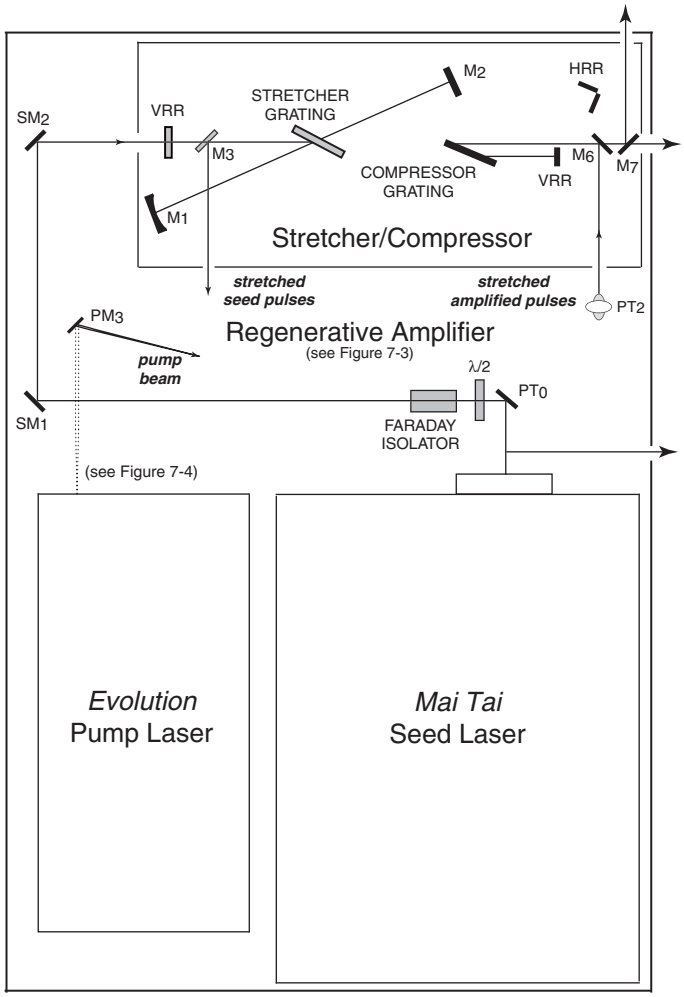


Figure 7-1: *Hurricane i* Beam Path

The treatment of the beam and its path through the *Hurricane i* are described in the following sections. For clarity, a number of simple optical

elements in the *Hurricane i* (apertures, beam expanding lenses, etc.) have been omitted from these diagrams. Also omitted for clarity are the spectrometer (in the stretcher/compressor cavity) and its optical elements.

The abbreviations used in Figure 7-1 are used throughout this manual to identify optical components.

A few of the more complex elements require some initial description:

Faraday Isolator—uses the polarization properties of the beam to protect *Mai Tai* optical components. Combined with the half-wave plate ($\lambda/2$), it absorbs any back-reflected power that is generated in the amplifier and absorbs pulses that are not selected for amplification.

Polarizer—is an optical element that, as used in the *Hurricane i* regenerative amplifier, is transparent to horizontally polarized light and reflects vertically polarized light. It directs the amplified pulse from the regenerative amplifier into the compressor.

Tall Stretcher End Mirror—is a mirror in the stretcher that is about 95% reflective so that 5% of the beam transmits through and is detected by the bandwidth detector (BWD) photodetectors located behind the mirror. It reflects the beam back onto the gold mirror.

Vertical Retroreflector—is a pair of flat mirrors at right angles that shift the beam upwards about one inch and reflect it back on a parallel path. There is a vertical retroreflector in the stretcher and one in the compressor.

Horizontal Retroreflector—is a pair of flat mirrors at right angles in the compressor that shift the beam sideways about two inches and reflect it on a parallel path.

This assembly is mounted on a translational stage that has a dc motor and motion control to adjust the output pulse compression. This adjustment allows compensation for variations in the group velocity dispersion (GVD) that may be experienced by the optical pulse while it is in the amplifier.

The Mai Tai Beam Bath

The beam height of the *Mai Tai* is adjusted to the correct height for the *Hurricane i* by periscope PT0. The beam then passes through the combination of the half-wave plate ($\lambda/2$) and Faraday Isolator. This arrangement prevents feedback from the beam path from reflecting into the *Mai Tai*, which would produce instabilities in its mode-locked operation.

The seed beam is then directed into the stretcher via two alignment mirrors (SM_1 and SM_2).

The initial *Mai Tai* output is horizontally polarized, but the above combination of optics rotates the beam so that it arrives in the stretcher with horizontal polarization.

The Stretcher and Compressor Beam Paths

Although the beam passes from the stretcher into the regenerative amplifier *before* returning to the compressor, the treatment of the beam in both the stretcher and compressor is similar. Thus, these components are described together first.

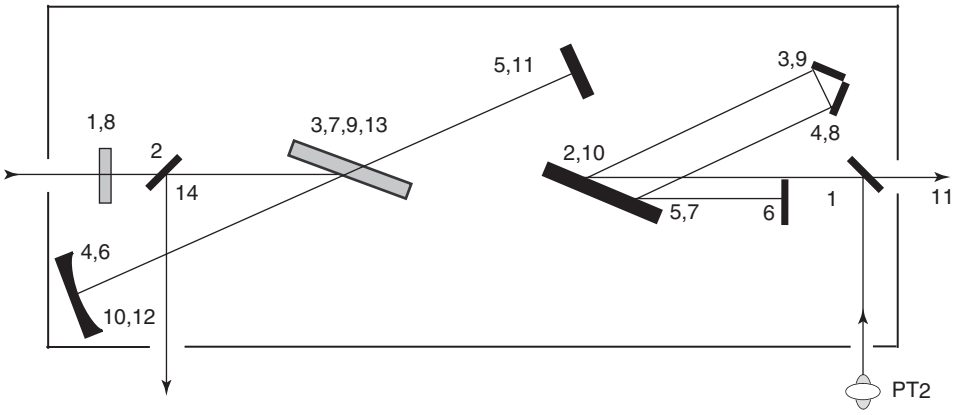


Figure 7-2: Pulse Stretcher and Compressor Beam Sequencing

Note

Numbers are used in the following drawing to track the path of the beam as it passes from optic to optic; they *are not* used either to name the optic itself or indicate the position of the beam on the optic. Refer to Figure 7-1 for the abbreviations used for the optical components.

Stretcher

1. The input beam passes through a gap (1) in the vertical retroreflector VRR, *over* the pick-off mirror M_2 (2) and onto the stretcher diffraction grating (3).
2. The grating disperses the beam spectrally, with the redder wavelengths to the right and the bluer wavelengths to the left, and reflects the diverging beam onto the center of the concave gold mirror M_1 (4).
3. The concave gold mirror is angled slightly upward to reflect the beam *over* the grating onto the tall stretcher end mirror M_2 (5).
4. The beam is then reflected back *over* the grating again to the concave mirror (6) and returned to the grating (7).
5. The grating reflects the beam toward the bottom of the vertical retroreflector (8). The path of the redder wavelengths is longer than that of the bluer wavelengths and, therefore, lags behind of the bluer wavelengths.
6. The vertical retroreflector shifts the beam upwards and reflects it back to the top of the grating (9), passing through the stretcher one more time (10, 11, 12).
7. Because the beam hits low on the concave mirror, it is reflected to the bottom of the grating (13), and as it leaves the grating it is low enough to be picked off by M_3 (14) and sent out of the stretcher.

Compressor

After amplification in the Ti:sapphire cavity, the pulsed beam enters the compressor. Continue to refer to Figure 7-1 for the symbols for the optical components.

1. The polarization rotating periscope PT_2 changes the beam to horizontally polarized and directs it into the compressor (see Figure 7-3). The beam is directed to the compressor turning mirror M_6 (1).
2. The beam reflects onto the right side of the compressor grating (2).
3. The grating spreads the temporally broadened beam with the redder wavelengths on the right and the bluer wavelengths on the left, and reflects the beam towards the horizontal retroreflector (3).
4. The horizontal retroreflector shifts the beam over about two inches (4), flips the ends of the spectrum, and returns the beam to the lower left side of the grating (5). The redder wavelengths now take the shorter path.
5. The beam reflects off the grating and travels to the vertical retroreflector (6).
6. The beam is stepped upwards an inch and is sent back to the top left side of the grating (7), which reflects it to the upper part of the right horizontal retroreflector (8).
7. The horizontal retroreflector flips the beam around again (9) and sends it back to the grating (10) where the beam is finally combined as a round compressed beam and reflected toward the exit *over* M_6 (11).
8. When the pulse exits the compressor, it has been compressed close to the duration of the seed pulse.

The Ti:Sapphire Regenerative Amplifier

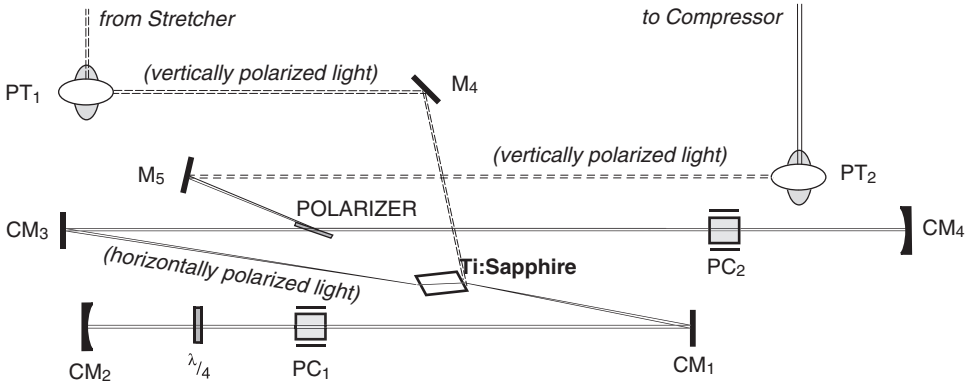


Figure 7-3: Regenerative Amplifier Beam Path (pump beam not shown)

The Seed Beam Path

1. Horizontally polarized pulses from the stretcher are rotated to vertical polarization by the polarization rotating periscope PT_1 and directed into the amplifier cavity by M_4.

2. The Ti:sapphire rod, cut at Brewster's angle for horizontally polarized light, reflects the vertically polarized pulses off its surface and directs them toward the first cavity mirror CM_1.

At this point, the pulsed beam is in the amplifier cavity. Whether a pulse is selected to remain in the cavity is determined by the input Pockels cell. When this Pockels cell is off, it is transparent to both vertically polarized and horizontally polarized light. When a Pockels cell is on, it acts together with $\lambda/4$ to rotate the polarization of the beam from horizontal to vertical, or vice versa.

Depending on the state of the input Pockels cell, one of three things will now happen:

Case (a)—if the input Pockels cell is off when the pulse arrives, the pulse passes through the cell and is reflected back to the same Pockels cell. If this Pockels cell is still off when the pulse returns, the pulse is rejected after one round trip through the amplifier.

Case (b)—if the input Pockels cell is on when the pulse arrives, the pulse is not selected and is rejected without passing through the Ti:sapphire crystal.

Case (c)—the input Pockels cell is off when the pulse arrives but is turned on after the pulse travels through it and before the pulse is reflected back to the same cell. The pulse is now selected. The pulse makes about 20 round trips in the cavity, gaining in amplitude with each pass, and is released into the compressor by activating the output Pockels cell.

Each case is examined in detail below.

Note

As long as the selected pulse remains horizontally polarized, it remains in the cavity. Whenever a pulse arrives at the Ti:sapphire crystal as vertically polarized, it is ejected.

Pulse selection is accomplished by the combining the polarization rotating properties of the passive quarter-waveplate ($\lambda/4$) with the transmission properties of the input Pockels cell. Pulses at 1 kHz (or 5 kHz) repetition rate are selected for amplification while the remaining megahertz seed pulses are rejected.

The synchronized timing for the firing of the Pockels cells is provided by the *SDG II*.

Case (a): the input Pockels cell is off and stays off (the pulse is rejected).

3. The vertically polarized pulse reflects off CM_1, passes through an aperture, through the inactive input Pockels cell and is rotated 45° as it passes through $\lambda/4$. It reflects off CM_2 and rotates another 45° as it passes through $\lambda/4$ again.
4. Now, horizontally polarized, the pulse passes through the inactive input Pockels cell again, through the aperture and again reflects off CM_1. Because it is now horizontally polarized, it passes through the Ti:sapphire rod and picks up first-pass gain.

5. The pulse continues to CM_3, is reflected through the horizontal polarizer and passes through an aperture and through the inactive output Pockels cell.
6. The pulse reflects off CM_4, passes back through the inactive output Pockels cell again, goes through the aperture, through the horizontal polarizer, reflects off CM_3 and passes back through the Ti:sapphire rod for second pass gain.
7. The next part of the journey is just like that in Steps 3 and 4, except that now, because the polarization of the pulse is rotated another 90° by two passes through $\lambda/4$, it is vertically polarized. It is reflected off the surface of the Ti:sapphire rod and out of the amplifier cavity, back to M_4.

   Once rejected, the pulse passes back through the stretcher and is absorbed by the Faraday isolator.

Case (b): the input Pockels cell is already on (pulse is rejected).

8. As before, the incoming vertically polarized pulse reflects off CM_1 and passes through an aperture. But this time, as it passes through the now active input Pockels cell, it is rotated 45° by the cell and another 45° as it passes through $\lambda/4$, becoming horizontally polarized.

   But after reflecting off CM_2, the pulsed beam is rotated another 45° by $\lambda/4$ and another 45° by the still active input Pockels cell and it returns to vertical polarization. It passes through the aperture, reflects off CM_1, reflects off the Ti:sapphire surface and is ejected out of the cavity.

Case (c): the input Pockels cell is off and is then turned on (the pulse is selected).

9. The soon-to-be-selected pulse comes into the cavity and becomes horizontally polarized as outlined in Step 3 of Case (a). This time, however, after the pulse passes back through the inactive Pockels cell and travels toward CM_2, the input Pockels cell is turned on. (The output Pockels cell remains off for now.)

   The pulse remains in the cavity because it remains horizontally polarized (since the input Pockels cell is on, the pulse is flipped 180° each time it traverses the input path, leaving its polarization unchanged). The pulse is amplified each time it passes through the crystal.

   The pulses that follow behind the selected pulse arrive with the input Pockels cell already turned on and remain vertically polarized as in Case (b) and are discarded.

10. After the selected pulse has passed through the crystal about 20 to 25 times, it has reached its optimum amplification. The output Pockels cell is now turned on just before the pulse returns to it (the precise timing is set by the *SDG II*).

    The pulse now finds the output Pockels cell acting as a quarter-wave-plate, so it is rotated 45° going in and 45° again when reflected back from CM_4. The pulse is thus vertically polarized and is reflected out of the cavity by the horizontal polarizer.

11. The vertically polarized, amplified pulse is reflected by the polarizer to mirror M_5.
12. The pulsed amplified beam is expanded by a telescope comprising a negative and a positive lens (not shown) and is thus enlarged to reduce pulse power density to protect the compressor optics.
13. The expanded beam is directed into the compressor by the polarization rotating periscope PT_2 that changes the vertically polarized light from the amplifier to horizontally polarized light.
14. M_6 directs the beam into the compressor chamber (see Figure 7-1).

The Pump Beam Path

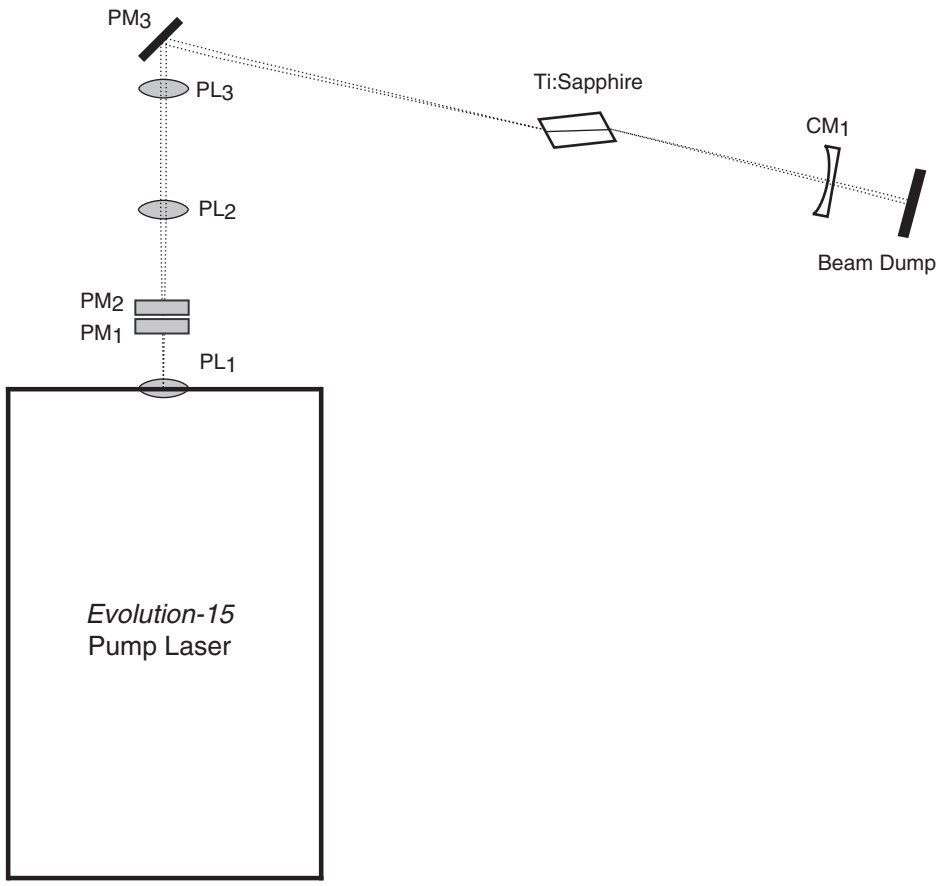


Figure 7-4: Pump Beam Path

The green 527 nm light from the Q-switched Nd:YLF *Evolution-15* laser is horizontally polarized so that it can enter into and be absorbed by the Ti:sapphire rod. Roughly 80% of the pump beam is absorbed by the rod. The pump beam traces a path through the following optical elements:

The beam is translated to the correct height for the *Hurricane i* chassis by a periscope made up of mirrors PM_1 and PM_2. Lenses PL_1, and PL_2 comprise a telescope that enlarges the pulsed beam from the *Evolution-15* by a factor of 4 so that it can be better focused into the Ti:sapphire rod. The pump beam should be centered on pump lens PL_3.

PL_3 focuses the pump beam into the Ti:sapphire rod, and the beam is directed to the rod by turning mirror PM_3.

The fraction of the high power pump beam that is *not* absorbed by the Ti:sapphire rod transmits through the rod onto CM_1. CM_1 does not reflect a significant amount of 527 nm light and the pump beam passes through it and is absorbed by the beam dump behind it.

Chapter 8 Maintenance and Service

Exceptional care must be taken when operating the *Hurricane i* with the covers removed. The output beam can be very dangerous. Protective eyewear at must be worn to protect from all laser wavelengths.

Defeating the Cover Interlocks

Several of the procedures described in this chapter call for the *Hurricane i* and its component lasers to be operated with the covers removed and the safety interlocks defeated. If you are inexperienced at making adjustments to high-power infrared laser systems, do not proceed with these instructions. Instead, please contact your Spectra-Physics representative.

Shut down the system following the procedure described in Chapter 5 and remove the cover from the *Hurricane i*. Removing the cover activates two microswitches at the corners of the *Hurricane i* frame that deactivate the diode laser arrays that pump the *Evolution-15*. With the *Evolution-15* deactivated, the regenerative amplifier will also remain off.

The cover interlock on the *Hurricane i* **does not** deactivate the *Mai Tai* seed laser.

There are four "interlock defeats" supplied with the *Hurricane i*, each comprised of a 1 in. square aluminum plate and a captive screw. Two of these must be screwed into the upper frame of the *Hurricane i* to depress the cover interlock microswitches and allow the *Evolution-15* and the regenerative amplifier to resume lasing when the system is turned back on. (The remaining two interlock defeats are for use with the *Evolution-15* cover itself. Removing the *Evolution-15* cover is not required by the procedures in this chapter.)

Follow the procedure in Chapter 5 for starting the system. Recall that there is a delay between the time that the system is first energized and the emission of laser light.

After completing the maintenance and adjustment procedures, follow the shut-down procedure listed in Chapter 5. Remove the interlock defeats and replace the *Hurricane i* cover.

Troubleshooting Guide

This troubleshooting guide is provided to assist you in isolating some of the problems that might arise, for example, if performance drops unexpectedly. A complete alignment and repair procedure is beyond the scope of this manual. This guide should help provide information to your Spectra-Physics service representative to assist in obtaining more advanced service, if required.

Symptom: Emission light comes on, but no output

Possible Cause:	Corrective Action:
Pockels Cells Inactive	Check that the LEDs on the SDG II are on for OUT 1 DELAY and OUT 2 DELAY.
BWD interlock open	Check the two LEDs for the BWD on the *SDG II*. If both diodes are on, reset the interlock button of the BWD. If both diodes are not on, check the *Mai Tai* to make sure the laser is mode-locked and the wavelength is centered as specified. Reset the interlock button of the BWD after restoring *Mai Tai* operation.
Mai Tai is not functioning correctly	Refer to *Mai Tai User's Manual* for further instructions.
Evolution-15 is not functioning correctly	Refer to *Evolution-15 User's Manual* for further instructions.
Seed beam is misaligned	Optimize the *Mai Tai* alignment as described on page 8-7.

Symptom: Regenerative amplifier power is below specification

Possible Cause:	Corrective Action:
Optics are dusty	Clean all optics, with particular attention to the pump path and regenerative amplifier optics, using the procedure on page 8-6.
Optics are damaged	Check the optical components in the regenerative amplifier. If an optic has been damaged, contact your Spectra-Physics representative to arrange to have the optic changed. It may be possible to use an undamaged portion of the optic face and realign the regenerative amplifier as a temporary solution.
Seed beam is misaligned	Optimize the *Mai Tai* alignment as described on page 8-7.
Evolution-15 power is low	Optimize the *Evolution-15* power according to the *Evolution-15 User's Manual*.
Compressor is misaligned	Check alignment of the compressor (see page 8-10).
Timing is incorrect	Check settings for OUT 1 DELAY and OUT 2 DELAY on the *SDG II*.
Pump beam is misaligned	Optimize the alignment of the pump beam (see page 8-11).

Symptom: Pulse has broadened out of specification

Possible Cause:	Corrective Action:
Compressor delay is not optimized	Adjust the compressor motor controller to get the shortest pulse.
Seed pulses are broadened	Check the *Mai Tai* bandwidth and center wavelength.
Evolution-15 pump power is low or unstable	See troubleshooting guide in *Evolution-15 User's Manual.*
Stretcher misalignment is broadening pulses	Check the alignment of the stretcher. Check the seed beam alignment to make sure it is optimized (see page 8-7).
Timing is incorrect	Check the settings for OUT 1 DELAY and OUT 2 DELAY

Symptom: Output power is unstable

Possible Cause:	Corrective Action:
There is power variation in the *Evolution-15* pump	See troubleshooting guide in *Evolution-15 User's Manual*.
There is power variation in the regenerative amplifier	Check the settings for OUT 1 DELAY and OUT 2 DELAY.

EV Fault Software Indicators

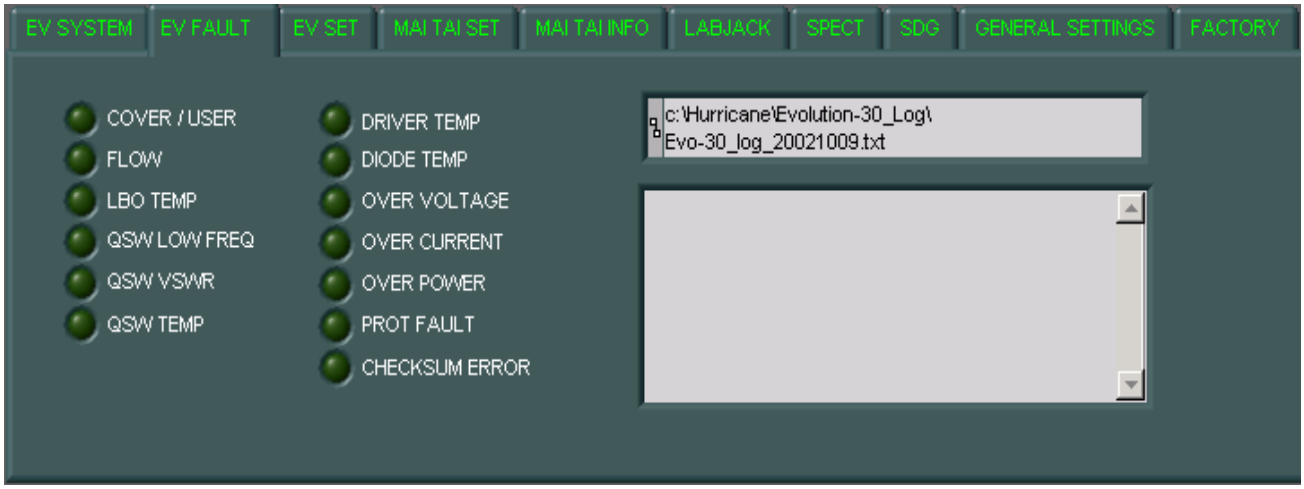


Figure 8-1: The EV Fault Panel

A number of faults that may occur can be corrected by the user, as indicated in the following table. The *Hurricane i* will need to be restarted after the fault is cleared.

Table 8-1: Fault Indicators, *Evolution-15*

LED	Indication	Corrective Action
COVER/USER	Remote interlock on the power supply or a laser head micro-switch is tripped	Check interlocks
FLOW	Chiller flow < 2.0 GPM	Verify that the chiller is functioning properly, the water pressure and reservoir levels are correct and the hoses are not kinked, then cycle the keyswitch to clear the fault.
LBO TEMP	LBO temp > preset factory set point	*Evolution-15* enters countdown mode to allow temp to return to range before lasing resumes.
QSW LOW FREQ	QSW MODE is set to EXTERNAL and the external trigger source drops below 500 Hz	Ensure that the trigger source is producing TTL pulses at 500 Hz or higher.
QSW VSWR	QSW RF connectors on the *Evolution-15* power supply are disconnected	Check connections.
QSW TEMP	AOM overtemp	Verify the chiller is functioning properly, water pressure and reservoir levels are correct, and water hoses are not kinked, then cycle the keyswitch to clear the fault.
DRIVER TEMP	Diode laser driver (FET) heat sink overtemp	Check airflow in the *Evolution-15* power supply. Allow the system to run without lasing for at least 10 minutes to cool it down, then restart the laser.

Table 8-1: Fault Indicators, *Evolution-15*

LED	Indication	Corrective Action
DIODE TEMP	*Evolution-15* pump chamber is overtemp	Turn off the *Evolution-15* power supply. Allow the chiller to run for 10 minutes to cool down the power supply, verify the chiller temperature is correct, then restart the laser, running it at a lower diode laser drive current.
OVER VOLTAGE	Diode laser is over-voltage	Check the umbilical connection, and cycle the power on the power supply to clear the fault.
OVER CURRENT	Diode laser array is over-current	Lower the current drive setting, then cycle the power on the power supply to clear the fault.
OVER POWER	Diode laser drive FET exceeds the factory-set power limit	Reduce the diode laser drive current, then cycle the power on the power supply to clear the fault.
PROT FAULT	Diode laser drive FET protection circuit is activated	Shut down the Hurricane i system and contact Spectra-Physics. Do not operate the Evolution-15 if a PROT FAULT error occurs!
CHECKSUM ERROR	Communication error for the Evolution-15	If infrequent, these can be ignored. If they occur frequently, check the RS-232 cable connections.

Cleaning the Optics

Do not attempt to clean the optics while laser light is circulating in the *Hurricane i*. Shutter the *Mai Tai* beam; shutter the *Evolution-15* beam if the cover interlocks have been defeated.

The following materials are required:

- Reagent grade methanol or acetone
- Lens tissues
- Hemostat (surgical pliers)
- Eyedropper

The gold mirror and the gratings *cannot* be cleaned, other than by blowing dust from their surfaces with dry nitrogen. Do not allow anything to touch the surfaces of these optics or they may be permanently damaged.

Optics should be carefully cleaned with soft optical tissue and reagent grade methanol or acetone as follows:

1. Wash your hands to remove all dirt and oil residues.
2. Wear finger cots at all times when handling optics.
3. Hold one sheet of lens tissue over the optic to be cleaned.
4. Place a single drop of methanol on top of the lens tissue.
5. Drag the lens tissue across the optic only once.
6. If a residue of solvent is left on the optic, repeat the procedure using less solvent and a new lens tissue until no residue remains.

For hard to reach optics:

1. Wear finger cots or gloves.
2. Fold a piece of lens tissue to form a pad approximately 1 cm wide.
3. Hold the pad with a hemostat so that only the folded edge protrudes.
4. Saturate the pad with methanol or acetone and shake off the excess solvent.
5. Reach slightly onto one edge of the optic and wipe the surface of the optic toward the outside in one motion. Be careful that the tip of the hemostat does not scratch the optic.

Performance Optimization

The parameters that should be optimized for good performance of the *Hurricane i* are:

- Stability of the mode-locked pulse train
- Alignment of the *Mai Tai* beam into the regenerative amplifier
- Regenerative Amplifier performance
- Compressor optimization
- Alignment of the *Evolution-15* beam into the regenerative amplifier

Caution!

The procedures described in this section are for the convenience of technical personnel who are experienced in maintaining and adjusting high power infrared lasers. They should not be attempted by someone who is inexperienced at these tasks.

Aside from being dangerous, improper application of these procedures may result in damage to the *Hurricane i* that will not be covered by your warranty. If you have any question about your ability to follow these procedures, please do not hesitate to contact your Spectra-Physics representative.

Pulse Train Stability

The stability of the mode-locked pulse train must be kept optimized to ensure the stability of the regenerative amplifier. Please refer to the *Mai Tai User's Manual*.

The duration of the input pulse is particularly important. If the pulse duration is too long, pulse stretching will be insufficient and optical damage to the *Hurricane i* could occur. The pulse duration and spectrum should be kept within specification.

Seed Beam Alignment

Refer to Chapter 7 for diagrams of the *Hurricane i* optical layout.

Verify the *Evolution-15* laser is off. Turn on the *Mai Tai* (if necessary) and allow it to warm up thoroughly.

1. Use the IR card or IR viewer to check the alignment of the *Mai Tai* beam into the regenerative amplifier. It is possible that the beam has drifted slightly since the *Hurricane i* was last operated. The beam is injected into the regenerative amplifier after first reflecting off one face of the Ti:sapphire rod. The beam should be aligned so that it is centered on the aperture in front of the first Pockels cell (PC_1). The beam should pass through PC_1 and reflect back down the resonator, through all the optics (including the Ti:sapphire rod) to cavity mirror CM_4.
2. Use the IR card or IR viewer to ensure that the beam is clearly visible at CM_4. Make slight adjustments to the input mirror M_4, *not* the cavity mirrors, until you see a beam centered on the aperture in front of the second Pockels cell (PC_2).

If you cannot see the beam, it will be necessary to check its alignment through the stretcher, as follows:

3. Rotate the gratings out of the beam path and use the IR card to ensure that the beam is well aligned through the apertures at the entrance to the stretcher and the exit from the compressor.
4. Rotate the gratings to their original positions and use an IR viewer to look at the beam pattern on the stretcher grating. It should look like the pattern in Figure 8-2:

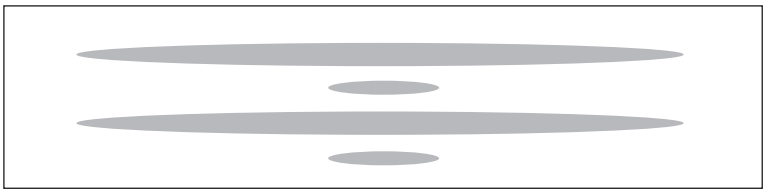


Figure 8-2: Radiation Pattern on Stretcher Grating

If the beam pattern does not look like Figure 8-2, it is likely that the wavelength of the *Mai Tai* laser has changed or the grating is rotated incorrectly. In order to return to previous operating conditions, verify that the *Mai Tai* wavelength is the same as it was during prior operation, then rotate the grating until the pattern is symmetrical on the grating as shown in the diagram. If you cannot obtain the pattern shown above, contact your Spectra-Physics' representative.

5. The output beam from the stretcher should now be picked off by mirror M_3. It may be necessary to *slightly* adjust the height of the stretcher mirror using the micrometer.
6. Align the beam into the regenerative amplifier as described in the next section.

Regenerative Amplifier Optimization

Note

In the following procedure, the regenerative amplifier is initially operated as a Q-switched laser pumped by the *Evolution-15*.

1. Block the *Mai Tai* beam from entering the regenerative amplifier cavity.
2. Turn on the *Evolution-15* and allow it to warm up.
3. Disable OUT 2 DELAY. The regenerative amplifier will begin to operate as a laser.
4. Monitor the intracavity radiation using REGEN TRANS PD on the umbilical panel of the *Hurricane i* (see Figure 8-3, and refer to the section "Rear (Umbilical) Panel" on page 3.).

Note

Use a fast oscilloscope with a micro channel plate screen or a digitizing oscilloscope with a sampling speed greater than 2 giga-samples per second. Trigger the oscilloscope externally from the *SDG II* SYNC OUT DELAY. Set the time-base to 100 or 200 ns/div. Use a 50 W input impedance for the photodiode.

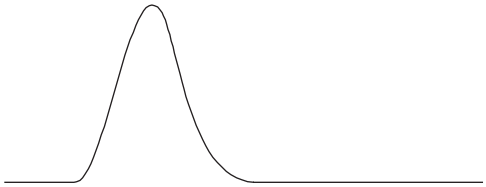


Figure 8-3: Appearance of Q-switched Pulse

5. Remove the business card blocking the seed beam. The energy of the *Mai Tai* pulses will now overcome the energy of the spontaneous emission in the Ti:sapphire rod in the regenerative amplifier so that it now amplifies the seed pulses. The intracavity radiation will now appear something like the pattern shown in Figure 8-4, below.

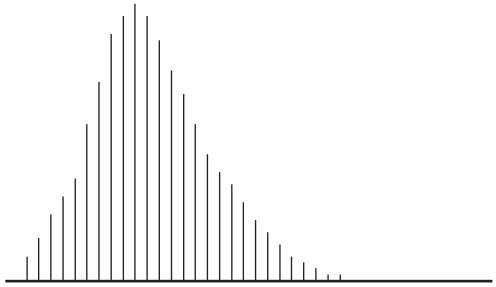


Figure 8-4: Intracavity Pulse Train

6. While monitoring the pulse train, adjust the M_4 turning mirror that directs the seed pulse into the resonator. Reduce the pulse build-up time to the minimum possible; that is, adjust M_4 so that the pulse train moves to the left on the oscilloscope screen.
7. Adjust the *SDG II* OUT 2 DELAY until the intracavity pulse train looks like that in Figure 8-5.

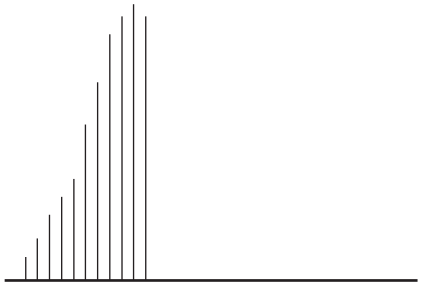


Figure 8-5: Intracavity Pulse Train with Correct Timing

8. Connect the REGEN OUT PD output of the *Hurricane i* to an oscilloscope. You should see a single, stable output pulse. Refer to the description in the section "Rear (Umbilical) Panel" on page 3.
9. While viewing the output mode, adjust mirror PM_2 to obtain the roundest and most homogenous mode.
10. If the pulse amplitude is stable but there is evidence of a secondary pulse, make a slight adjustment to the OUT 2 DELAY control. If this does not produce a stable and single cavity-dumped pulse, adjust the OUT 1 DELAY control by ±10 ns. If a stable single cavity is still not produced, contact your Spectra-Physics service engineer.

Compressor Adjustment

The alignment of the beam through the compressor should remain stable. To optimize compressor performance, first confirm that the output beam is round and even in intensity. Then look at the radiation pattern on the compressor grating with an IR viewer. The pattern should look like that shown in Figure 8-6.

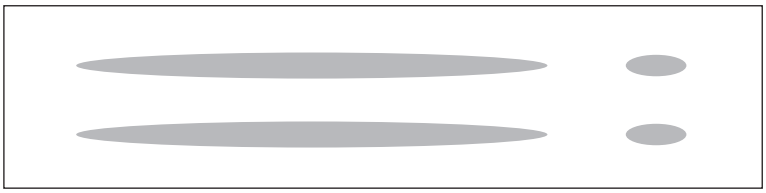


Figure 8-6: Radiation Pattern on Compressor Grating

Note

The components referred to in this procedure are shown on the figures in Chapter 7, "Optical Layout."

1. Install the removable aperture in the holder near M_6.
2. Install the second aperture in the holder between the grating assemblies.
3. Adjust PT_2 to center the beam on the first aperture.
4. Rotate the compressor grating so that the beam passes by it and strikes the second aperture.
5. Adjust M_6 to center the beam on the second aperture.
6. Iterate Steps 3 and 5 until the beam is centered on both apertures.
7. Rotate the compressor grating back into position. The beam pattern on the grating should look like the pattern shown in Figure 8-6. If it does not, be certain the compressor grating has been properly rotated back to its original position.
8. Set the compressor length for optimum compression as described in Chapter 6, "Operation."

Alignment of the Pump Beam

Note

In the following procedure, the regenerative amplifier is initially operated as a Q-switched laser pumped by the *Evolution-15*.

This procedure assumes that the *Evolution-15* pump laser is operating properly. Please refer to the *Evolution-15 User's Manual* for details of operation. The path of the pump beam is shown in Figure 7-4.

1. Close the shutter for the *Mai Tai* laser.
2. Set the *Evolution-15* power to 15 A.
3. Use the mirror PM_2 to center the green beam through PL_2 and PL_3.
4. Use PM_3 to direct the beam to the center of the Ti:sapphire rod.
5. To measure the output power of the regenerative amplifier, place the detector for a power meter in the beam between PT_2 and M_6. (The shutter located in this position will have to be removed temporarily.)
6. Place a target (typically a white business card) in front of PT_2.
7. On the *SDG II*, enable OUT 1 DELAY and disable OUT 2 DELAY.
8. Connect an oscilloscope to view the output of REGEN OUT PD.
9. Set the *Evolution-15* to the appropriate power level for the *Hurricane i* and start the *Evolution-15*. (For correct power level, refer to the installation report provided with the *Hurricane i*.)
10. The amplifier resonator should now lase. If it does not, adjust the pump beam across the Ti:sapphire crystal face until the pump beam is superimposed onto the intracavity beam.

    The lasing status can be determined either by viewing the target in front of PT_2 with an IR viewer, or by monitoring (while using appropriate safety eyewear) the fluorescence of the Ti:sapphire amplifier crystal: the fluorescence decreases as the amplifier lases.
11. When the amplifier lases, while viewing the Q-switched pulse on the scope, adjust PM_3 to achieve the highest amplitude pulse with a corresponding minimum buildup time.
12. Enable OUT 2 DELAY and adjust its timing to cavity dump the maximum power from the cavity.
13. If the output mode is not symmetrical, make small adjustments to PM_3 to achieve symmetry.
14. Remove the target card and verify that the cavity dumped power agrees with the power achieved at installation for the given pump power. If necessary, make small adjustments to OUT 2 DELAY to achieve maximum cavity dumped power output when measured with the power meter as opposed to viewing the pulse on the scope.
15. If the power is still low, refer to "Troubleshooting Guide" on page 2.
16. The seed beam can now be injected, and its alignment and timing optimized for amplified output.

Customer Service

At Spectra-Physics, we take pride in the durability of our products. We place considerable emphasis on controlled manufacturing methods and quality control throughout the manufacturing process. Nevertheless, even the finest precision instruments will need occasional service. We feel our instruments have favorable service records compared to competitive products, and we hope to demonstrate, in the long run, that we provide excellent service to our customers in two ways. First, by providing the best equipment for the money, and second, by offering service facilities that restore your instrument to working condition as soon as possible.

Spectra-Physics maintains major service centers in the United States, Europe, and Japan. Additionally, there are field service offices in major United States cities. When calling for service inside the United States, dial our toll-free number: **1 (800) 456-2552**. To phone for service in other countries, refer to the Service Centers listing located at the end of this section.

Order replacement parts directly from Spectra-Physics. For ordering or shipping instructions, or for assistance of any kind, contact your nearest sales office or service center. You will need your instrument model and serial numbers available when you call. Service data or shipping instructions will be promptly supplied.

To order optional items or other system components, or for general sales assistance, dial **1 (800) SPL-LASER** in the United States, or **1 (650) 961-2550** from anywhere else.

Warranty

This warranty supplements the warranty contained in the specific sales order. In the event of a conflict between documents, the terms and conditions of the sales order shall prevail.

The *Hurricane i* is protected by a twelve (12) month warranty. All mechanical and optical parts and assemblies are unconditionally warranted to be free of defects in workmanship and material for the warranty period. At its election, Spectra-Physics will repair or replace without charge components that prove defective during the warranty period. The obligation of Spectra-Physics is limited to repair covered under the warranty return procedure described on the following page. Equipment repaired or replaced is warranted only for the remaining original warranty period.

This warranty is in lieu of all other warranties, implied or expressed, and does not cover incidental or consequential loss.

Spectra-Physics will provide at its expense all parts and labor and one way return shipping of the defective part or instrument (if required).

This warranty does not apply to equipment or components that, upon inspection by Spectra-Physics, discloses to be defective or unworkable because of abuse, mishandling, misuse, alteration, negligence, improper installation, damage in transit, or other causes beyond the control of Spectra-Physics.

Return of the Instrument for Repair

Contact your nearest Spectra-Physics field sales office, service center, or local distributor for shipping instructions or an on-site service appointment. You are responsible for one-way shipment of the defective part or instrument to Spectra-Physics.

We encourage you to use the original packing boxes to secure instruments during shipment. If shipping boxes have been lost or destroyed, we recommend you order new ones. Spectra-Physics will only return instruments in Spectra-Physics containers.

Warning!

Always drain the cooling water from the laser head and/or power supply before shipping. Water expands as it freezes and will damage the unit. Even during warm spells or summer months, freezing may occur at high altitudes or in the cargo hold of aircraft. Such damage is excluded from warranty coverage.

Service Centers

Benelux

Telephone: (31) 40 265 99 59

France

Telephone: (33) 1-69 18 63 10

Germany and Export Countries*

Spectra-Physics GmbH
Guerickeweg 7
D-64291 Darmstadt
Telephone: (49) 06151 708-0
Fax: (49) 06151 79102

Japan (East)

Spectra-Physics KK
East Regional Office
Daiwa-Nakameguro Building
4-6-1 Nakameguro
Meguro-ku, Tokyo 153
Telephone: (81) 3-3794-5511
Fax: (81) 3-3794-5510

Japan (West)

Spectra-Physics KK
West Regional Office
Nishi-honmachi Solar Building
3-1-43 Nishi-honmachi
Nishi-ku, Osaka 550-0005
Telephone: (81) 6-4390-6770
Fax: (81) 6-4390-2760
e-mail: niwamuro@splasers.co.jp

United Kingdom

Telephone: (44) 1442-258100

United States and Export Countries**

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1330 Terra Bella Avenue
Mountain View, CA 94043
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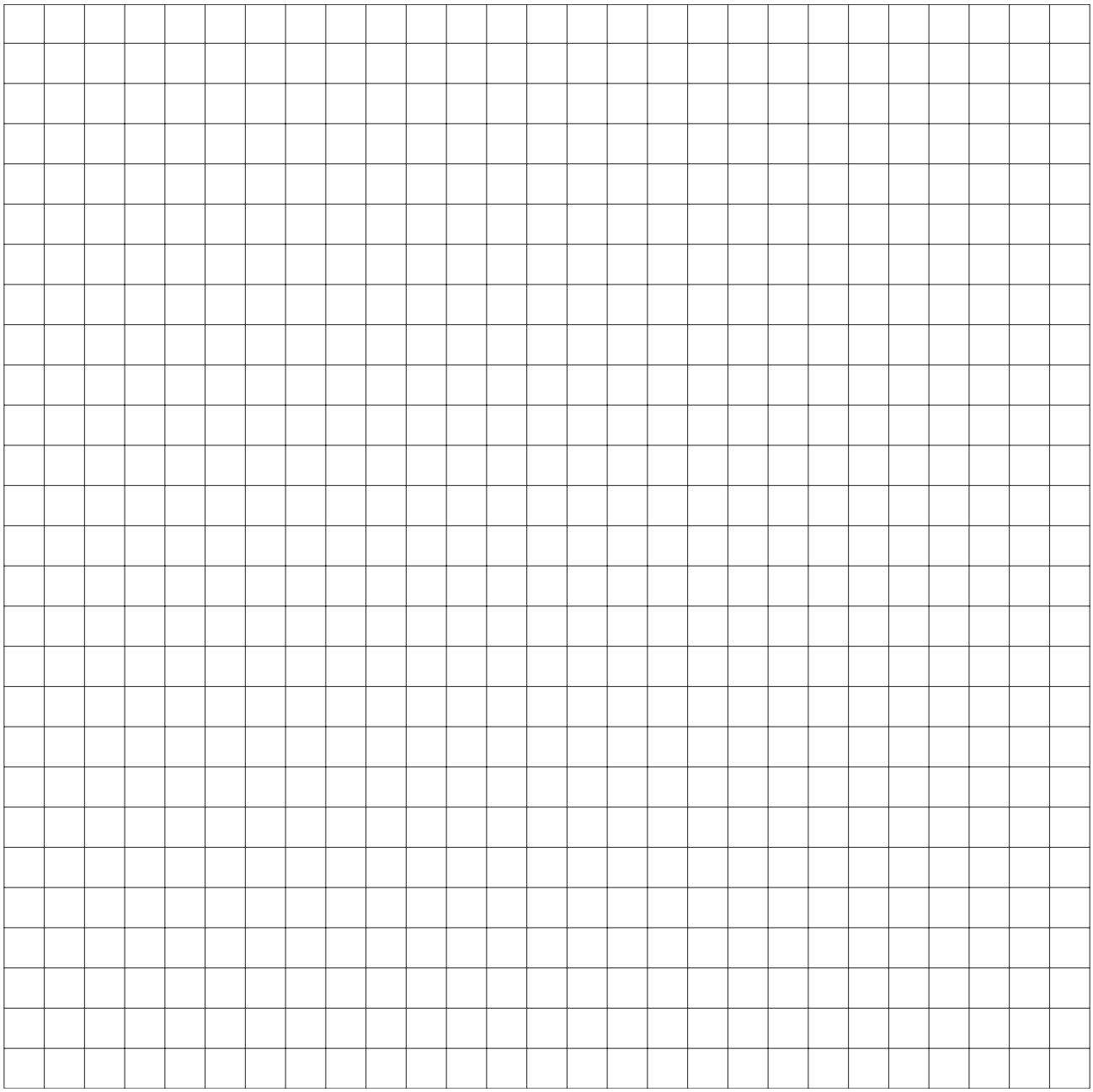
(800) SPL-LASER (Sales) or
(800) 775-5273 (Sales) or
(650) 961-2550 (Operator)
Fax: (650) 964-3584
e-mail: service@splasers.com
sales@splasers.com
Internet: www.spectra-physics.com

**And all European and Middle Eastern countries not included on this list.*
***And all non-European or Middle Eastern countries not included on this list.*

Notes



Report Form for Problems and Solutions

We have provided this form to encourage you to tell us about any difficulties you have experienced in using your Spectra-Physics instrument or its manual—problems that did not require a formal call or letter to our service department, but that you feel should be remedied. We are always interested in improving our products and manuals, and we appreciate all suggestions.

Thank you.

From:

Name _____

Company or Institution _____

Department _____

Address _____

_____

Instrument Model Number _____ Serial Number _____

Problem: _____

_____

_____

_____

_____

Suggested Solution(s): _____

_____

_____

Mail To:

Spectra-Physics, Inc.
SSL Quality Manager
1330 Terra Bella Avenue, M/S 15-50
Post Office Box 7013
Mountain View, CA 94039-7013
U.S.A.

E-mail: sales@splasers.com
www.spectra-physics.com

FAX to:

Attention: SSL Quality Manager
(650) 961-7101